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FINAL REPORT

CONTRACT NAS8-33465

COMMERCIALIZATION OF THE POWER FACTOR CONTROLLER

(NASA-CR-171500) COMMERCIALIZATION OF THE POWER FACTOR CONTROLLER Final Report (Iveco, Inc.) 362 p HC A16/MF A01 CSCL 09C N85-28221

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PREPARED BY

IVECO, INC.

5762 RESEARCH DRIVE

HUNTINGTON BEACH, CA 92647

FOR

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

APRIL 15, 1981

Edward Yrisarri, Jr.

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IVECO INC.

IMPROVEMENT VIA ELECTRONICS

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TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICIES

A	Workstatement Contract NAS8-33465
B	Report Requirements, Contract NAS8-33465
C	UL Technical Submittal
D	NASA Tech Brief, MFS 23280
E	SIC Codes
F	Triac vs HP
G	NASA Patent 4,052,648
H	Typical Current Curves for 15A, 25A, 30A, 40A, 60A, and 80A Triacs
J	Thermal Analysis, 3ϕ Controllers, 100°F
K	Thermal Analysis, 3ϕ Controllers, 150°F
L	Energy Savings
M	Cost/Price Breakdown

REFERENCES

1 Classification and Evaluation of Electric Motors and Pumps
U.S. Department of Energy
Report No. DOE/TIC-11339 September 1980

2 Instruments & Control Systems - December 1979
James V. Yu, "Motors and Your Electric Bill"

3 Machine Design - February 22, 1979
Louis Zacherl, "Protecting Electric Motors"

4 Technical Support Package
MFS23280 June 30, 1975
Frank Nola, "Power Factor Controller"

1.0 INTRODUCTION

This is a final report culminating a design/study program for "Commercialization of the Power Factor Control Unit", NASA contract No. NAS8-33465 between NASA/MSFC, Huntsville, Alabama, and IVECO (Improvement Via Electronics), Huntington Beach, California. The contract was a Cost-Share type wherein IVECO (the contractor) was reimbursed for not more than 34.9% of the cost of performance under the contract. Total liability of NASA was $38,310.00, with a total performance limitation of $109,754.00. Deliverable end-items under the terms of the contract were six (6) packaged single-phase controllers capable of accommodating up to 5 HP at 240V, and twelve (12) packaged three-phase controllers capable of accommodating 10 HP at 480V, plus this final report. The Scope of Work is delineated in Exhibit "A", paragraph III.B.5 of the contract. The contract work statement, referred to above, is delineated in its entirety in Appendix A of this report. Table 1 is a list of the items requiring determination as a result of this contract. Appendix B shows the reporting requirements of this contract.

TABLE 1

TO BE DETERMINED
o POTENTIAL THIS CIRCUIT HAS FOR SAVING ENERGY
o COST TO PRODUCE THE DEVICE - BOTH SINGLE AND 3 PHASE
o COST EFFECTIVENESS OF APPLYING THE DEVICE

TABLE 1 (CONT.)

- CAN THE DEVICE AID IN CUTTING COSTS CHARGED FOR A POOR POWER FACTOR? CAN IT REPLACE CAPACITORS AND SYNCHRONOUS MOTORS USED FOR CORRECTION.
- IN CERTAIN APPLICATIONS CAN THE DEVICE DOUBLE AS THE POWER CONTACTOR FOR THE MOTOR?
- CAN THE DEVICE SERVE AS A MEANS OF LIMITING STARTING INRUSH CURRENT IN LARGE MOTORS?
- POTENTIAL FOR REDUCING AIR CONDITIONING COSTS.
- HOW SERIOUS IS THE PROBLEM OF CONNECTING TO THE WYE POINT OF 3 PHASE WYE MOTOR?
- IS THE WYE POINT AVAILABLE IN LARGER MOTORS?
- EFFECT ON UTILITIES DISTRIBUTION SYSTEM
- IS THE SAVINGS TO THE UTILITY COMPANY SIGNIFICANT?
- STABILITY NEEDS TO BE ANALYZED
- ABILITY TO RESPOND TO STEP TYPE LOADING NEEDS TO BE STUDIED AND IMPROVED
- IN SOME CASES THE CAPACITOR REQUIRED FOR STABILITY NEEDS TO BE LARGER THAN THAT REQUIRED FOR FILTERING. THIS SLOWS THE RESPONSE.

In addition, preliminary investigation and UL approval by Underwriters Laboratories, Inc. on the design and packaging components of the hardware developed under the contract was a requirement. This is still underway. The UL technical submittal is included with this report as Appendix C. IVECO selected seven (7) separate industrial/public sector organizations for installation, testing, and demonstration of the effectiveness of the controllers developed. Three (3) of these installations involved single-phase motors, and the other four (4) involved three-phase motors. Difficulties during the course of field testing have resulted in several iterations of the three-phase controllers. Not all testing was completed at contract duration end (12-31-80); however, the unfinished tests will be accomplished by IVECO and an addendum will be furnished to NASA/MSFC. The tests are expected to be completed by 6-30-81. Section 4.0 of this report discusses the tests completed and their results thus far.

At the outset of the program, IVECO identified areas of design/development previously undertaken by IVECO (i.e. prior to contract) which are directly applicable to the controllers and involved proprietary designs. Such areas of development were identified in Paragraph I "DESCRIPTION OF ORGANIZATION PERFORMANCE", of Report No. 1. The IVECO prior achievements are listed below (excerpt from Report No. 1):

A. The controller can be used on either "delta" or "wye" wound motors.

B. No physical connection to the motor "neutral" is necessary.

C. The controller can be placed physically distant from the motor of application (i.e., at a convenient junction box).

D. Current sensing in lieu of voltage sensing is employed to minimize heat dissipation.

E. A single adjustment only is necessary to set up all three phases of operation.

F. Motor balance is accomplished by relating each phase control to the other two phases.

2.0 GENERAL DISCUSSION

Electric motors are devices that convert electrical energy into mechanical energy: sometimes efficiently, sometimes not efficiently.

Figure 1 shows an electric motor family tree. The overwhelming majority of all AC motors employed are AC induction squirrel-cage motors. There are approximately 99,000 different combinations of characteristics (end-class) of AC squirrel-cage induction motors in the 1/6 to 500 HP range.[1] Figure 2 shows a breakdown of these classifications. Total end classification of all motors would probably run into hundreds of thousands. Figure 3 shows the percentage of annual energy use of electric motors by end users. Figure 4 shows the percentage of electrical energy consumption by motors by user categories.

Approximately 58% of all U.S. electrical energy is used to power approximately 750 million motors in this country. In the non-residential sectors of the U.S. economy, this percentage rises to 80%; more than 90% in industries such as mining, primary metals, and electric utilities themselves.

Ninety percent of the motor population, however, are small fractional horsepower units used principally in households. They, surprisingly, account for only 2½% of the total motor drive energy use. The 5 to 125 HP range, constituting only 1.8% of the motor population, accounts for almost one-half of the

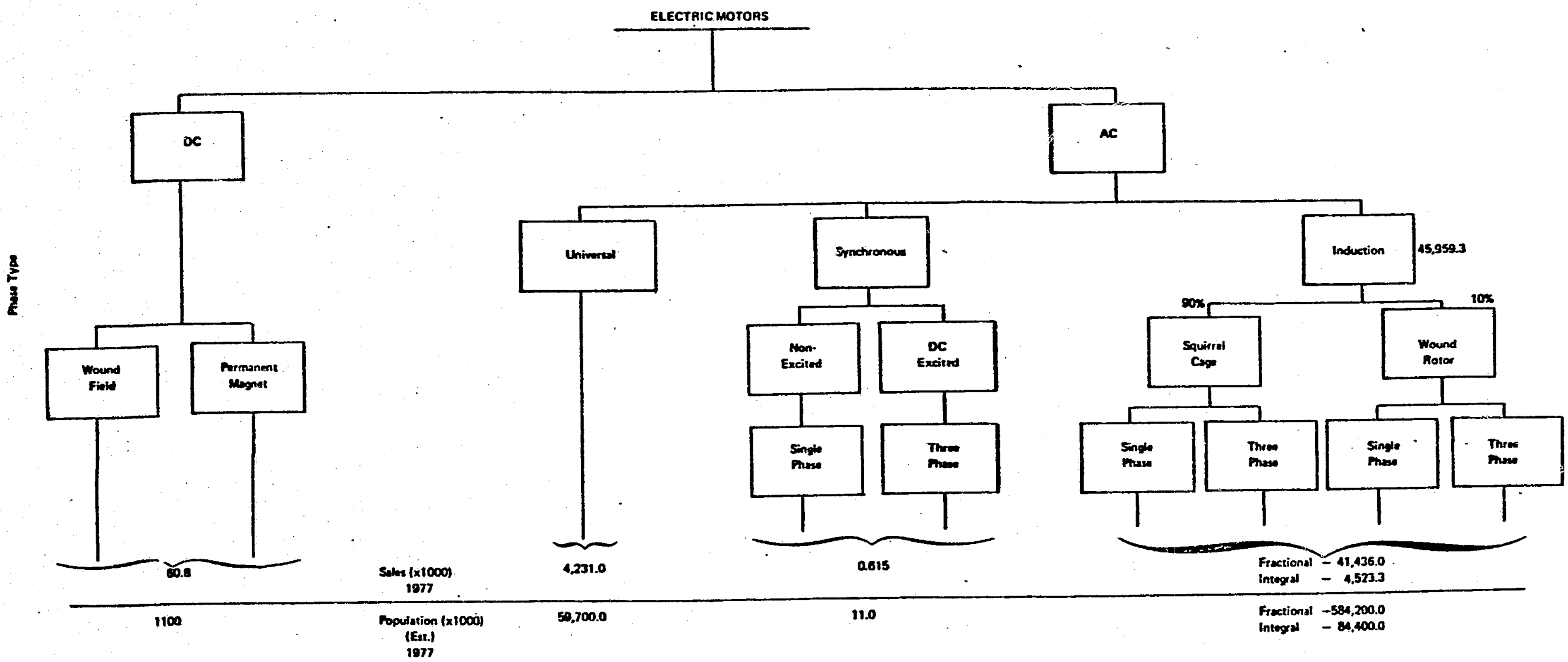

Figure 1 Electric Motor Family Tree

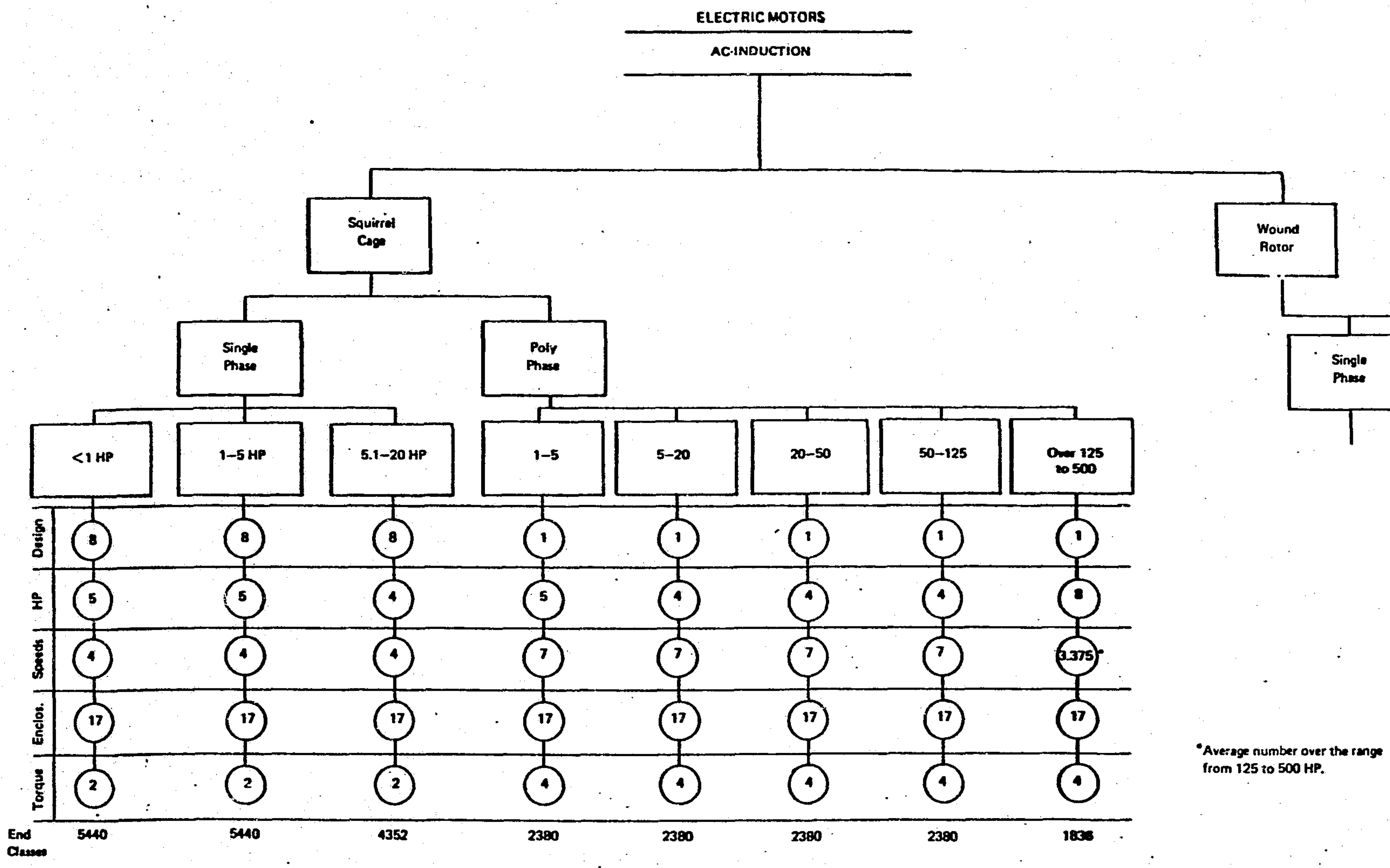

Figure 2 Classification of Squirrel-Cage AC Induction Motors

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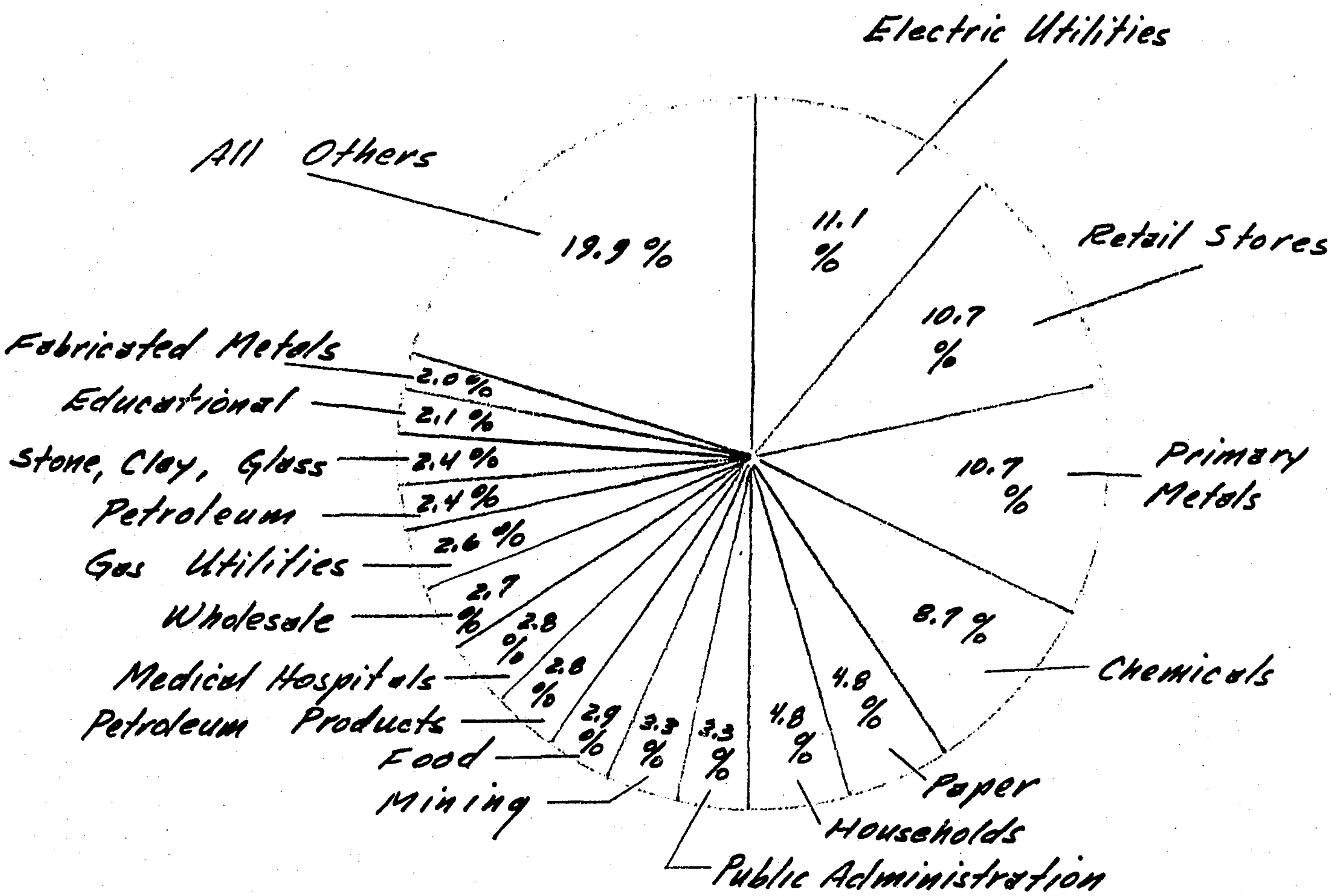

Figure 3

Percentage of Annual Electric Energy Use By Electric Motors

By End User Category

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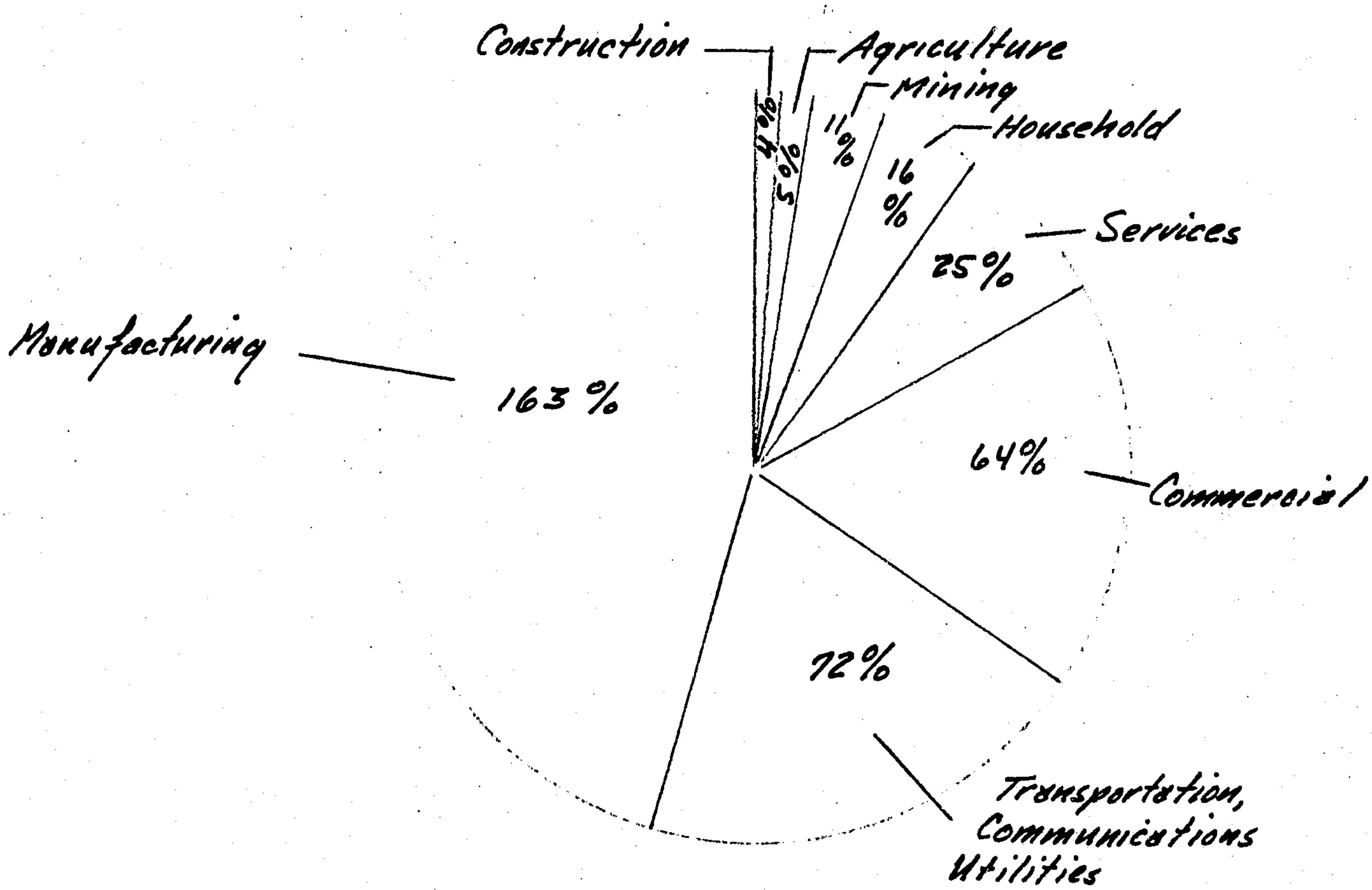

Figure 4

Percentage of Electric Energy Consumption

By Electric Motors By User Category

total motor drive energy use.

2.1 POWER FACTOR

Motor efficiency is a measure of the mechanical work output versus electrical power input.[2] A motor's efficiency is the percentage of electrical energy put into mechanical work. The remainder is heat loss, typically referred to as "watts loss". A motor's power factor measures how much current it draws. A motor uses real power (measured in kilowatts) to perform work, and reactive power (measured in volt-amperes-reactives, or VAR's) to provide a magnetizing force. These two (2) power components form a right-angle triangle which is shown in Figure 5. The hypotenuse of the triangle is apparent power (measured in volt-amperes). The power factor is the ratio between real power and apparent power (kW/kVA) expressed as a percent. The cost of operating a motor depends on both its efficiency and its power factor. Efficiency determines how much is charged for the real power needed to run the motor. Often, an electric utility charges penalties for power factors below 85% and/or a kVA demand. This is because an electric utility must generate the total current (kVA) needed, but is paid only for kW consumed. For example, if a motor has a low power factor, the utility must provide more kVA capability than would otherwise be required; thus, a penalty is charged.

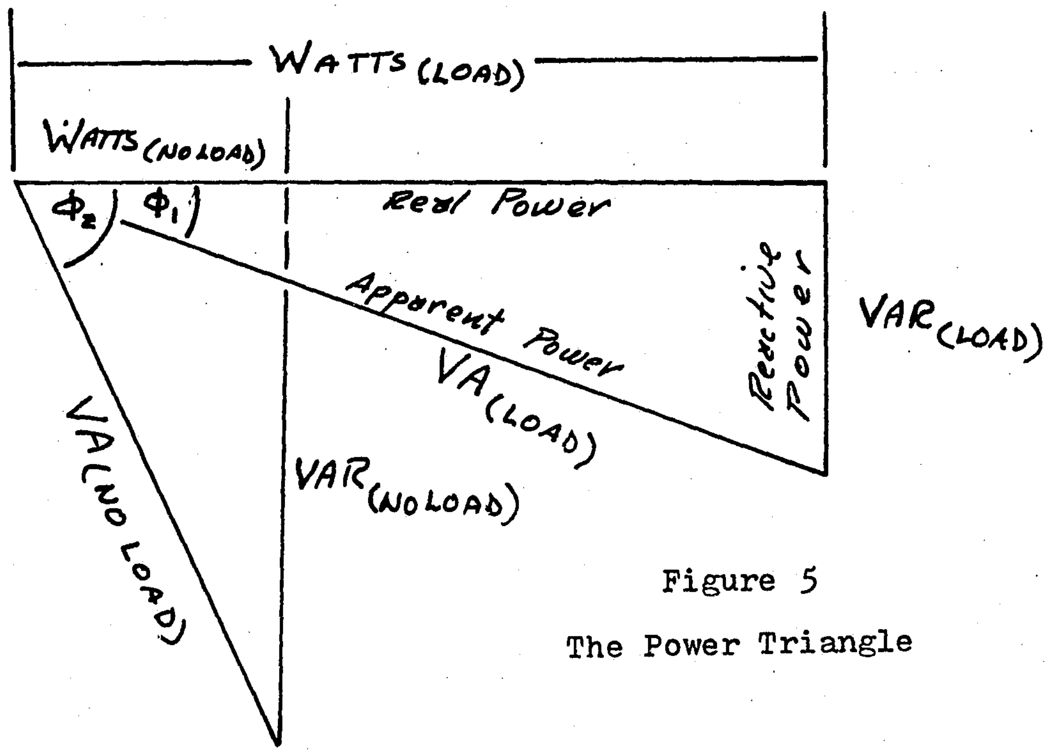

Figure 5

The Power Triangle

When load on a motor decreases, say from full load to no load, the power requirement decreases, but the angle increases, thus causing a decreasing power factor. As can be seen in the figure, while watts decrease, VAR's increase, and the percentage of power waste increases. This phenomenon can better be seen in Figure 6, load versus power/load versus power factor curves. For example, as load decreases from 100% to zero (0), power may typically reduce from 100% to 35%. The same figure shows that, while the power factor at full load may be 0.9, it deteriorates to 0.2 in some motors.

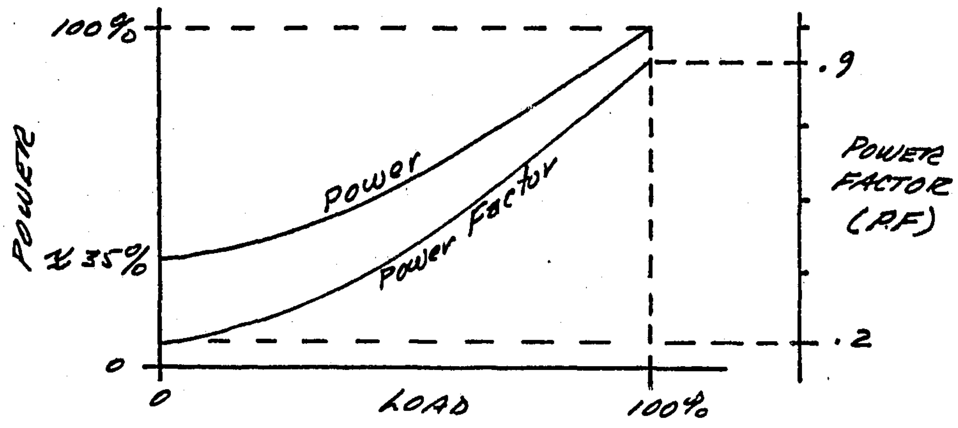

Figure 6

Load vs Power - Load vs PF Curves

2.2 THE MOTOR POWER CONTROLLER CONCEPT

The basic concept of the motor power controller (power factor controller) is to take advantage of an elemental motor action phenomenon. As load on a motor changes, there is a phase relationship change between the current and the voltage. This phase change is what causes the change in power factor. Power factor deteriorates with decrease in load and is maximum at full load. Since the power line can be considered an infinite voltage force, voltage remains constant and current is variable. Thus, current is proportional to load. A current monitor, therefore, provides an indication of loading conditions on the motor. The concept of the motor power controller is depicted in Figure 7.

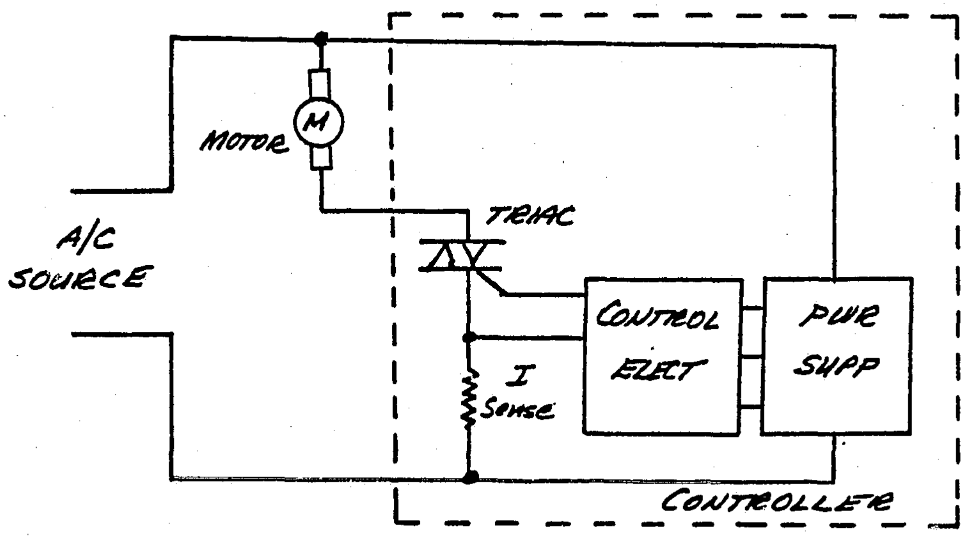

Figure 7

General Block Diagram

A triac (an electronic switch) is placed in series with the motor current. One (1) triac is required for single-phase motors, and three (3) triacs for three-phase motors (i.e., one (1) triac in each current leg of the motor). The triac, which is a solid-state switch, blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac switch remains ON until the current goes through zero (0). Current does not flow again until the gate voltage is again applied. Thus, the RMS voltage across the motor can be reduced (triggering the triac gate at a given point during the operating cycle) and allowing the triac to switch OFF as the current goes through zero (0). There are definite advantages to using a triac (or SCR)

as a static switch in AC circuits. It allows the control of relatively high currents with a very low power control source. Since the triac "latches" each one-half cycle, there is no contact bounce. Also, since the triac always opens at zero (0) current, there is no arcing or transient voltage developed due to stored inductive energy in the load or power lines. Appendix D encompasses NASA Tech Brief MFS-23280 describing the Power Factor Controller (herein refered to as the Motor Power Controller).

2.3 SAVING ENERGY WITH THE MOTOR POWER CONTROLLER

The basic questions here are: Can control of power factor (i.e., improvement) significantly affect energy consumption in motors? Has this contract demonstrated that applying the motor power controller to existing motor installations really reduced energy consumption primarily from the standpoint of user cost?

Table 2 shows the potential that, based on varying duty cycles of a motor, the power factor control can save energy. Equation 1 and its associated assumptions provide the derivation for the data in Table 2. The efficiencies shown below were obtained from the U.S. Department of Energy, Report No. DOE/CS-0147. Paragraph 3.11 of this report provides significant insight into the potential savings suggested here.

TABLE 2

3ϕ POTENTIAL kW SAVINGS

ITEM	HP	P_{FL} (kW)	P_{NL} (kW)	ΔP (kW)	DUTY CYCLE 20%	30%	40%	50%	60%	70%	80%
1	1	1.325	6.596	5.27	4.216	3.689	3.162	2.635	2.108	1.581	1.054
2	5	5.594	27.840	22.25	17.800	15.575	13.350	11.125	8.900	6.675	4.450
3	20	20.883	103.936	83.05	70.440	61.635	52.830	44.025	35.220	26.415	17.610
4	50	49.225	224.992	195.77	156.616	137.039	117.462	97.885	78.308	58.731	39.154
5	125	118.32	588.92	470.59	376.47	329.41	282.35	235.30	188.24	141.18	94.12

Eq. 1: $$P(kW) = \frac{\sqrt{3}\,(I)\,(V)}{10^3} = \frac{(0.746)\ Hp}{(p.f.)\ (eff)}$$

Assuming:

(a) $(p.f.)_{FL}$ at $30^o = \cos 30^o = 0.866$

(b) $(p.f.)_{3/4L}$ at $45^o = \cos 45^o = 0.707$

(c) $(p.f.)_{1/2L}$ at $60^o = \cos 60^o = 0.500$

(d) $(p.f.)_{1/4L}$ at $75^o = \cos 75^o = 0.259$

(e) $(p.f.)_{NL}$ at $80^o = \cos 80^o = 0.174$

Efficiencies:

HP	Efficiency[1]
1	0.650
1 - 5	0.770
5.1 - 20	0.825
21 - 50	0.875
51 - 125	0.910

Duty cycle is defined as the percentage of time that the motor is under load during one complete operational cycle. Since various motor applications exhibit various motor load profiles, it would be impossible to assume all possible conditions; therefore, the data shown in the Table assumes that a motor is either under full load or no-load. For example, 60% duty cycle means that the motor is under full load 60% of the time and under no-load 40% of the time. Figure 8 shows, in detail, the estimated motor population and electrical energy consumption by user category and SIC code.[1] Appendix E lists the SIC codes for end user categories.

Use Category	SIC	Less Than 1 hp Units (000's)	Less Than 1 hp Use Avg. (hr)	Less Than 1 hp Elec. Cons. 10^6 kW hr	1-5 hp Units (000's)	1-5 hp Use Avg. (hr)	1-5 hp Elec. Cons. 10^6 kW hr	5.1-20 hp Units (000's)	5.1-20 hp Use Avg. (hr)	5.1-20 hp Elec. Cons. 10^6 kW hr	21-50 hp Units (000's)	21-50 hp Use Avg. (hr)	21-50 hp Elec. Cons. 10^6 kW hr
Agricultural	01,02,07,08,09	5,000	250	261	2,500	1,000	2,507	600	1,000	3,874	400	1,000	7,758
Mining	10-14	450	500	47	150	800	120	70	2,000	904	36	4,000	2,715
Construction	15-17	3,000	250	157	1,000	500	501	20	500	65	10	500	97
Mfg. Non-Durable		1,655		207	1,730		2,276	2,060		24,405	510		47,133
Food	20	450	500	47	300	1,000	301	500	3,000	9,684	30	4,000	2,328
Textiles	22	175	500	18	175	1,000	175	200	2,000	2,583	40	3,000	2,328
Paper	26	225	800	38	250	1,500	378	150	3,000	2,905	45	6,000	5,237
Chemicals	28	250	800	42	350	2,000	702	700	3,000	13,588	200	6,000	23,275
Petroleum	29	65	800	11	65	2,000	130	200	3,000	3,874	45	6,000	5,237
Rubber	30	90	500	9	90	1,000	90	110	2,000	1,420	50	3,000	2,909
Other	21,23,27,31	400	500	42	500	1,000	501	200	2,000	2,583	100	3,000	5,819
Mfg. Durable		2,370		129	2,250		1,398	2,260		20,583	925		40,246
Furn. Lumb.	24,25	700	200	29	550	400	221	360	800	1,859	150	1,500	4,364
Stone	32	100	500	10	100	1,500	150	200	3,000	3,874	50	4,000	3,879
Prim. Metal	33	150	500	16	150	2,000	301	300	3,000	5,811	150	4,000	11,637
Fab. Metal	34	200	250	10	250	500	125	250	1,000	1,614	100	2,000	3,879
Non-Elec. Mach.	35	170	250	9	200	500	100	250	1,000	1,614	150	2,000	5,819
Elec. Mach.	36	250	250	13	200	500	100	250	1,000	1,614	125	2,000	4,849
Trans. Equip.	37	300	250	16	300	500	150	400	1,000	2,583	150	1,500	4,364
Other	38,39	500	250	26	500	500	251	250	1,000	1,614	50	1,500	1,455
Trans. Comm. Util.		2,002.5		290	452.5		1,080	181.5		4,407	92.5		8,932
Trans. Comm.	40,41,42,45,48	1,500	500	157	150	1,500	228	70	3,000	1,356	20	4,000	1,552
Pipelines	46	0.5	250	0	0.5	1,000	1	0.5	3,000	10	0.5	7,000	68
Elec. Util.	491	50	400	4	50	7,000	351	40	6,000	1,550	6	6,000	698
Gas Util.	492,493	50	400	44	50	2,000	100	30	3,000	581	40	6,000	4,655
Water	494,495,496	400	1,500	125	200	2,000	401	40	3,500	904	25	4,000	1,940
Irrigation	497	2	400	0	2	400	1	1	1,000	6	1	1,000	19
Commercial		18,500		1,932	2,950		2,367	3,750		24,211	720		20,948
Wholesale	50,51	1,000	500	104	500	800	401	500	1,000	3,228	180	1,500	5,237
Retail	52-59	9,000	500	940	1,600	800	1,284	2,500	1,000	16,141	400	1,500	11,638
FIRE	60-67	3,500	500	366	350	800	281	150	1,000	968	40	1,500	1,164
Pub. Ad.	43,91-97	5,000	500	522	500	800	401	600	1,000	3,874	100	1,500	2,909
Services		26,400		2,405	3,550		3,639	1,440		12,524	580		28,572
Hotels	70	5,500	800	919	400	2,000	802	150	1,000	968	65	1,500	1,891
Pers. Serv.	72	1,500	500	157	150	1,000	150	100	1,000	646	25	1,500	727
Auto	75,76	1,050	400	84	250	800	201	60	1,000	387	25	1,500	727
Recreat.	78,79	300	400	75	150	800	120	40	1,000	258	10	1,500	291
Medical	80	2,500	800	418	400	3,000	203	250	3,000	4,842	200	4,000	15,517
Educational	82	10,000	200	418	2,000	500	1,003	750	1,000	4,842	200	1,500	5,819
Other	73,81,83,84,86,89	4,000	400	334	200	800	160	90	1,000	581	55	1,500	1,600
Subtotal: All Except Hhlds		68,378		5,438	14,583		13,887	10,381		103,175	3,273		154,401
Households	88	~600,000	200	25,055	~40,000	500	20,066	40	1,000	284	40	1,000	776
Total		668,378		30,493	54,583		33,942	10,421		103,449	3,313		155,177
Avg. An. Units Consumed		50,976			3,186			538			152		
Avg. Life		12.9			17.1			19.4			21.8		
Rounded Total Units		500,000-800,000			50,000-60,000			9,000-13,000			3,000-4,000		
Avg. Life (yrs)		10-15			13-19			16-20			18-28		
Weighted Avg. Size (hp)		0.28			2.07			11.9			32.5		
Avg. Efficiency		0.65			0.77			0.825			0.875		
Avg. Load		0.70			0.50			0.60			0.70		

Figure 8a

Estimated Motor Population And Electricity Consumption (1977)

(Motors in Transportation Equipment Excluded)

Use Category	SIC	51-125 hp Units (000's)	51-125 hp Use Avg. (hr)	51-125 hp Elec. Cons. 10^4 kW hr	Greater than 126 hp Units (000's)	Greater than 126 hp Use Avg. (hr)	Greater than 126 hp Use Avg. (hp)	Greater than 126 hp Elec. Cons. 10^4 kW hr	Total Units (000's)	Motor Drive Total Elec. Cons. 10^6 kW hr	Total Elec. Cons. 10^4 kW hr	Percent Motor Drive to Total	Average Size (hp)
Agricultural	01,02,07,08,09	50	750	2,268	5	750	150	402	8,555	17,068	25,000	68	3.9
Mining	10-14	30	6,000	10,874	27	6,000	225	28,035	762	40,695	45,000	90	14.5
Construction	15-17	4	500	121	1.5	500	175	94	4,035.5	1,036	4,500	23	1.0
Mfg. Non-Durable		315		93,640	147.5			110,852	6,417.5	278,512	398,000	70	
Food	20	25	4,000	6,041	28	4,000	225	17,999	1,333	38,400	45,000	81	12.1
Textiles	22	40	3,000	7,250	30	3,000	175	11,249	660	23,603	30,000	79	19.4
Paper	26	50	6,000	18,124	31	6,000	250	33,213	751	59,893	74,000	81	21.2
Chemicals	28	100	6,000	36,248	35	6,000	225	33,748	1,635	107,573	171,000	63	19.7
Petroleum	29	30	6,000	10,874	12	6,000	175	9,000	417	29,126	35,000	83	20.9
Rubber	30	40	4,000	9,668	10	4,000	175	5,000	390	19,094	27,000	87	21.4
Other	21,23,27,31	30	3,000	5,437	1.5	3,000	200	643	1,231.5	15,026	21,000	73	7.9
Mfg. Durable		440		73,100	260			138,640	8,505	274,096	349,500	79	
Furn. Lumb.	24,25	50	2,000	6,041	12	2,000	175	3,000	1,822	15,514	21,000	74	9.3
Stone	32	30	4,000	7,250	20	4,000	250	14,285	500	29,448	32,000	92	23.7
Prim. Metal	33	80	6,000	28,998	80	6,000	250	85,710	910	132,473	172,000	77	39.3
Fab. Metal	34	50	2,000	6,041	45	2,000	175	11,250	895	22,919	27,000	85	21.2
Non-Elec. Mach.	35	70	2,000	8,458	36	2,000	175	9,000	876	25,000	31,000	81	23.6
Elec. Mach.	36	60	2,000	7,250	28	2,000	175	7,000	913	20,826	25,000	83	19.3
Trans. Equip.	37	70	1,500	6,343	38	2,000	200	8,143	1,258	21,599	32,000	76	19.1
Other	38,39	30	1,500	2,719	1	2,000	175	252	1,331	6,317	8,000	70	6.4
Trans. Comm. Util.		89		28,454	341			200,813	3,159	243,976	276,000	88	
Trans. Comm.	40,41,42,45,48	15	6,000	5,437	12	4,000	175	6,000	1,767	14,728	18,000	82	3.2
Pipelines	46	1	7,000	423	45	6,000	175	33,749	48	34,251	40,000	86	166.4
Elec. Util.	491	20	5,000	6,041	240	3,000	250	128,568	406	137,210	150,000	91	154.0
Gas Util.	492,493	40	6,000	14,499	11	6,000	250	11,785	221	31,624	37,000	85	38.2
Water	494,495,496	12	2,500	1,812	13	4,000	250	9,285	690	14,457	17,000	85	8.8
Irrigation	497	1	4,000	242	20	4,000	200	11,428	27	11,698	14,000	84	153.2
Commercial		590		106,931	126			62,996	26,636	219,385	296,000	74	
Wholesale	50,51	90	3,000	16,312	15	4,000	175	7,500	2,285	32,782	40,000	78	10.3
Retail	52-59	400	3,000	72,496	60	4,000	175	29,998	13,960	132,497	180,000	74	6.7
FIRE	60-67	30	3,000	5,437	11	4,000	175	5,500	4,081	13,716	16,000	86	2.3
Pub. Ad.	43,91-97	70	3,000	12,686	40	4,000	175	19,998	6,310	40,390	60,000	67	4.1
Services		155		18,728	72			24,445	31,197	88,313	115,000	77	
Hotels	70	20	2,000	2,417	6	4,000	175	3,000	6,141	9,997	12,000	80	1.5
Pers. Serv.	72	10	2,000	1,208	1	3,000	175	375	1,786	3,263	4,500	73	2.1
Auto	75,76	5	2,000	604	0	4,000	175	0	1,340	2,003	3,000	67	2.0
Recreat.	78,79	10	2,000	1,208	0	4,000	175	0	1,110	1,952	2,500	78	2.0
Medical	80	40	2,000	4,833	30	2,000	250	8,035	3,420	34,848	42,500	82	6.4
Educational	82	50	2,000	6,041	25	3,000	150	8,035	13,025	28,158	38,000	73	2.3
Other	73,81,83,84,85,89	20	2,000	2,417	10	4,000	175	5,000	4,375	10,092	14,000	72	1.8
Subtotal: All Except Hhlds		1,673		334,114	980			564,277	89,268	1,175,282	1,464,000	80	
Households	88	30	2,000	3,625	24	3,000	175	9,000	640,134	58,805	652,000	9	0.4
Total		1,703		337,739	1,004			573,277	729,402	1,234,087	2,116,000	58	
Avg. An. Units Consumed		59.7			34.3				54,946				
Avg. Life		28.5			29.3				13.27				
Rounded Total Units		1,400-2,000			800-1,200								
Avg. Life (yrs)		24-33			25-38								
Weighted Avg. Size (hp)		86.7			212								
Avg. Efficiency		0.91			0.94								
Avg. Load		0.85			0.90								

Figure 8b

Estimated Motor Population And Electricity Consumption (1977)

(Motors in Transportation Equipment Excluded)

3.0 TECHNICAL DISCUSSION

This section of the report delves into the technical detail of the motor power controller. Operational descriptions are followed by separate and specific detailed discussions on each of the pertinent paragraphs of the NASA Work Statement.

3.1 [4]THEORY OF OPERATION - SINGLE-PHASE MOTOR POWER CONTROLLER

Power losses in a motor are reduced by sensing the phase lag between the motor voltage and current and making corrections as these parameters tend to change their relationship with respect to each other. This information is fed to the electronic controller which forces the motor to run at a constant pre-determined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (i.e., triac or the equivalent) which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac remains ON until the current goes through zero (0). Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to the motor, the gate is triggered at a given point during the cycle, and the device switches OFF as the current goes through zero (0).

The reactive volt-amps of an induction motor is high when the motor is unloaded or partially loaded. Some motors tested showed unloaded current to be about 90 percent of the rated load current.

These currents cause heat losses in the motor.

Since the current remains high in an unloaded motor, the phase between the voltage and current shifts with load. Typically, the current may lag the voltage 80 degrees in an unloaded motor and 30 degrees when loaded. Figure 9 shows how the power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference between the two produces an error signal which biases a ramp voltage that is in sync with the 60 hertz line voltage. The intersection of the ramp and the error voltages is detected by a squaring amplifier whose output provides the time for turning-ON a triac (or SCR's) in the motor line.

Thus, the ON time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the timing diagram of Figure 10.

The phase angle shown as "θ" in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

When the circuit is in control of the motor current, voltage is applied to the motor for a portion of each positive and each

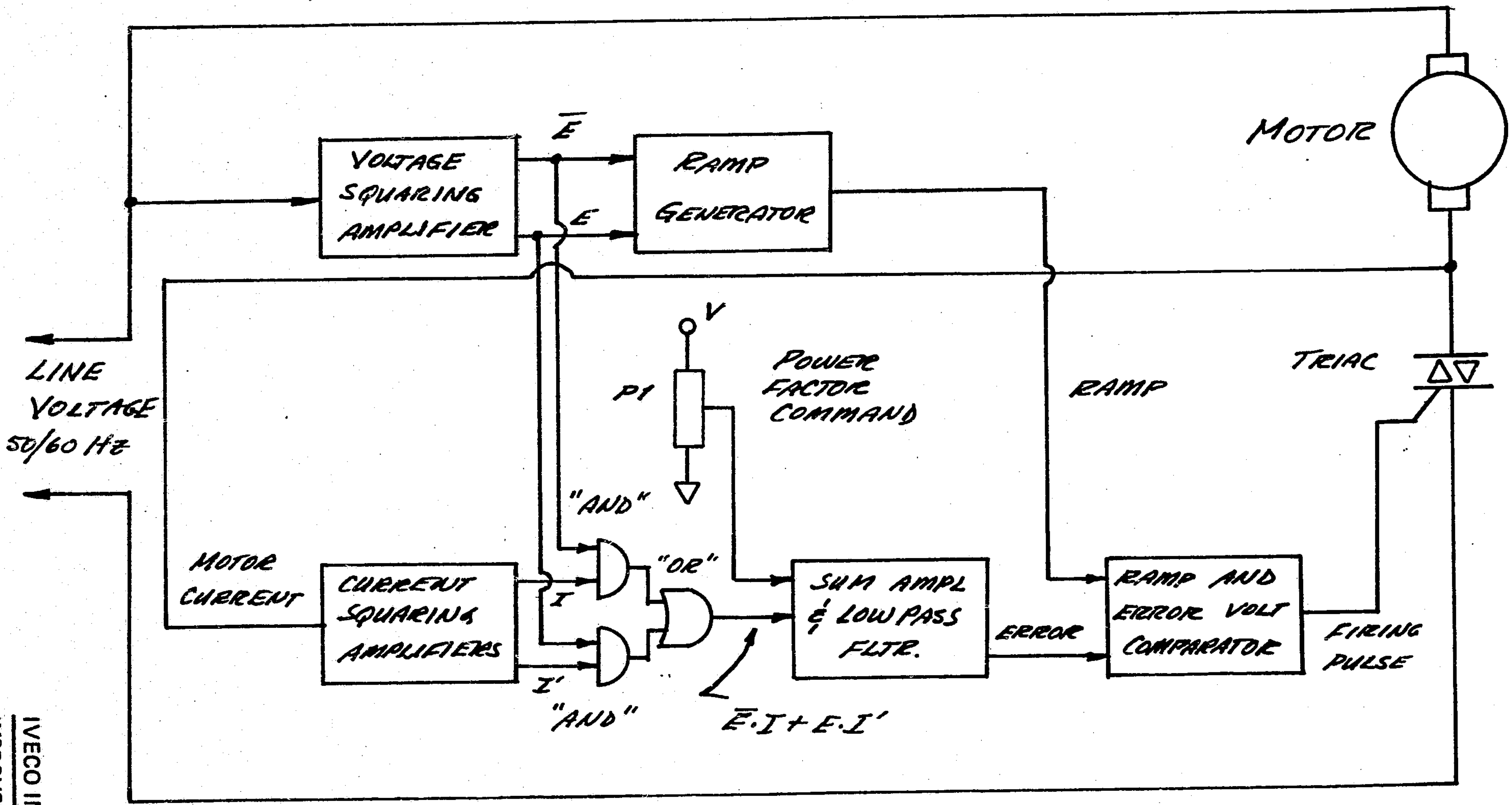

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Figure 9 Electrical Block Diagram

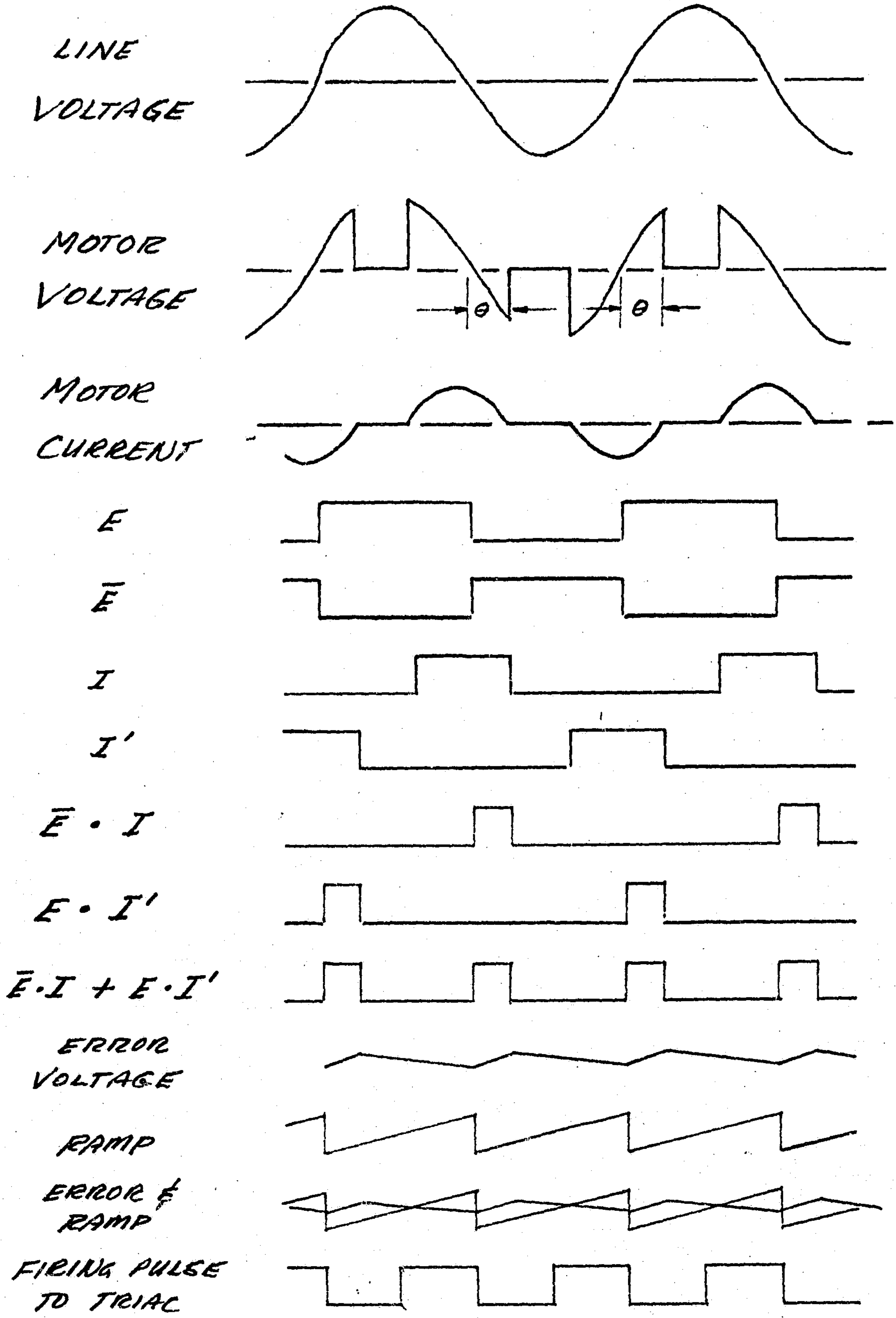

Figure 10

Timing Diagram

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negative half cycle of line voltage by means of the solid-state switch (triac) as seen in the timing diagram.

When the triac switches ON, rapid rise of the current is prohibited by the inductance of the windings. The current rises, reaches a peak, and then follows the voltage down as it approaches zero (0), but with a finite lag. Although the firing voltage to the triac goes to zero (0) when the line voltage goes through zero (0), the triac inherently will remain ON until the current goes through zero (0). This is shown by the motor voltage waveform.

The phase lag between voltage and current is indicated by "θ" in the timing diagram. This is the parameter which is to be measured and controlled. The line voltage and its inverse are squared by squaring amplifiers as indicated by E and $\overline{E}$ in the timing diagram. Each current pulse is squared by similar amplifiers as indicated by I and I'. By "AND'ing" $\overline{E}$ with I, and E with I' and then "OR'ing" the two, a pulse train is produced which has a pulse width proportional to the phase angle between voltage and current. When acted on by a low pass filter, the dc or average value of this voltage will be proportional to the phase angle. This voltage is summed with a command voltage from P1 (Electrical Block Diagram) which is indicative of a desired phase angle. The difference of the two is the system error voltage. This error is compared with a ramp which is synchronized with the zero crossings of the

line voltage. The intersection of the sloped portion of the ramp and the error voltage are detected by the comparator Q2 and form the turn ON pulse for the triac.

As the load on the motor is decreased, the slight change in phase angle causes the error to drop and intersect the ramp at a lower point. This moves the firing pulse to the right, along the sine-wave, causing the triac to turn ON for a shorter duration, lowering the applied voltage. Conversely, an increase in load will cause the firing angle to move to the left and apply more voltage to the motor. Thus, a phase anlge is commanded and the high gain of the feedback loop will vary the applied voltage to force the motor to operate at the desired phase angle regardless of load. Since the current is never higher than that required for a given load, motor losses are minimized.

A detailed electrical schematic of the EY1021 Motor Power Controller is shown in Figure 11. Resistor R 8 and Capacitor C 4 are used to reduce the EMI and RFI effects of the triac (or SCR) switching.

The difference in unit make-up for various horsepower involves changing triacs to accommodate larger current values and apply outside heat sinks commensurate with the power dissipated in the large triacs as a function of the motor horsepower. A chart showing triac versus horsepower is provided in Appendix F.

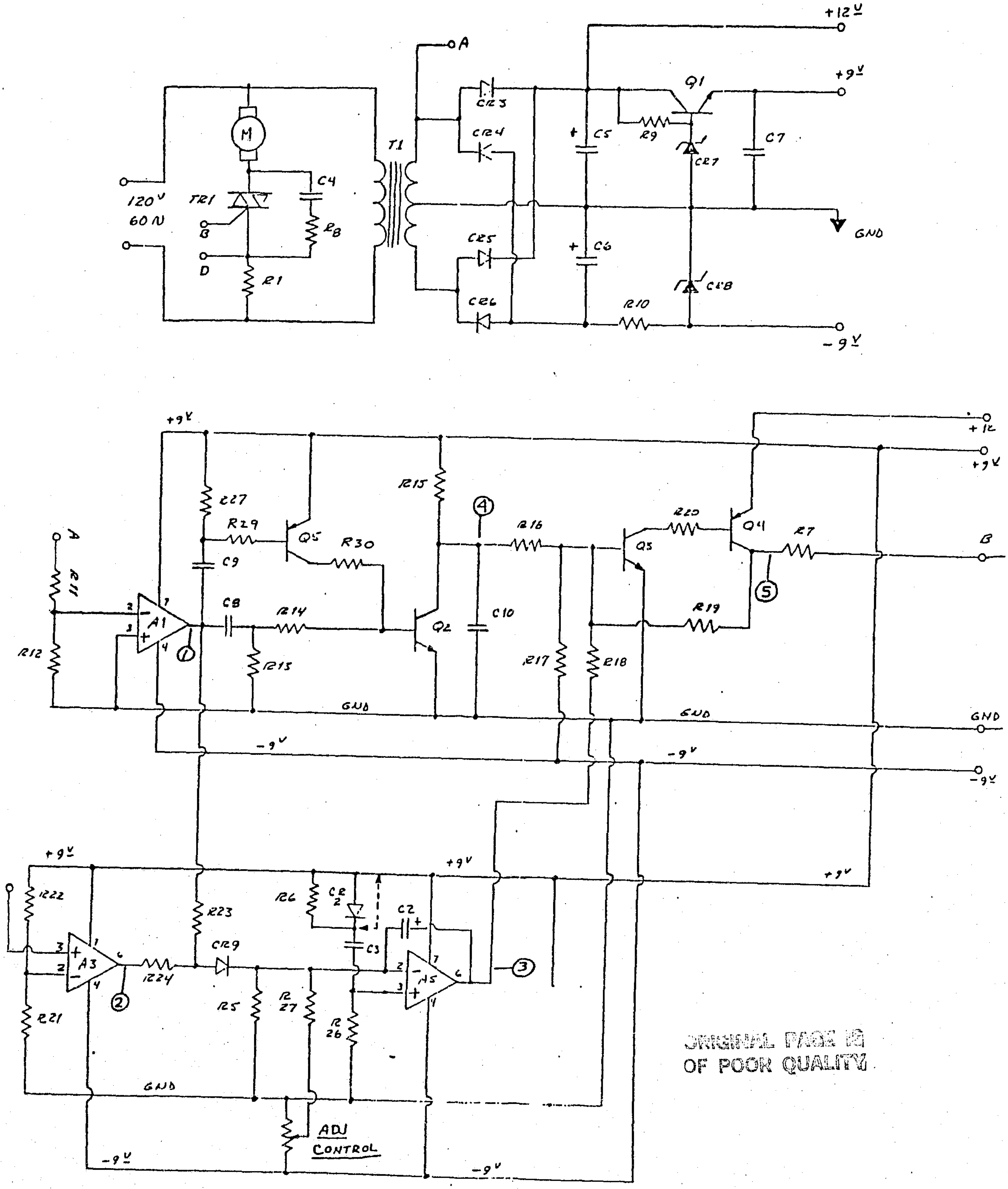

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Figure 11

Detailed Electrical Schematic

Model EY1021 Motor Power Controller

IVECO INC.

IMPROVEMENT VIA ELECTRONICS

Appendix G is a copy of the patent covering the power factor controller (Patent Number 4,052,648).

3.2 THEORY OF OPERATION - THREE PHASE MOTOR POWER CONTROLLER

A block diagram of the three-phase motor power controller is shown in Figure 12.

The philosophy of operation is similar to the single-phase motor power controller. In essence, the voltage and current of each phase is monitored and controlled.

In three-phase control, each of the three phases must be maintained in isolation from each other, yet in order to assure balanced control, the three phases must somehow be related. This is accomplished in the controller by electronically isolating voltage sensing, current sensing, and triac drive. With this isolation, the electronics can then relate phases to each other.

It is important to assure that control is balanced among the three phases so that under-controlling the motor phase currents remain balanced. This means that control of any phase must be related to the other two. Balance must also be maintained between ON-OFF demands positive to negative one-half cycle.

The three line voltages and currents are first squared-up and summed, thus producing a signal proportional to the phase angle between the current and voltage, indicative of the designed phase angle. The output error signal biases a ramp voltage

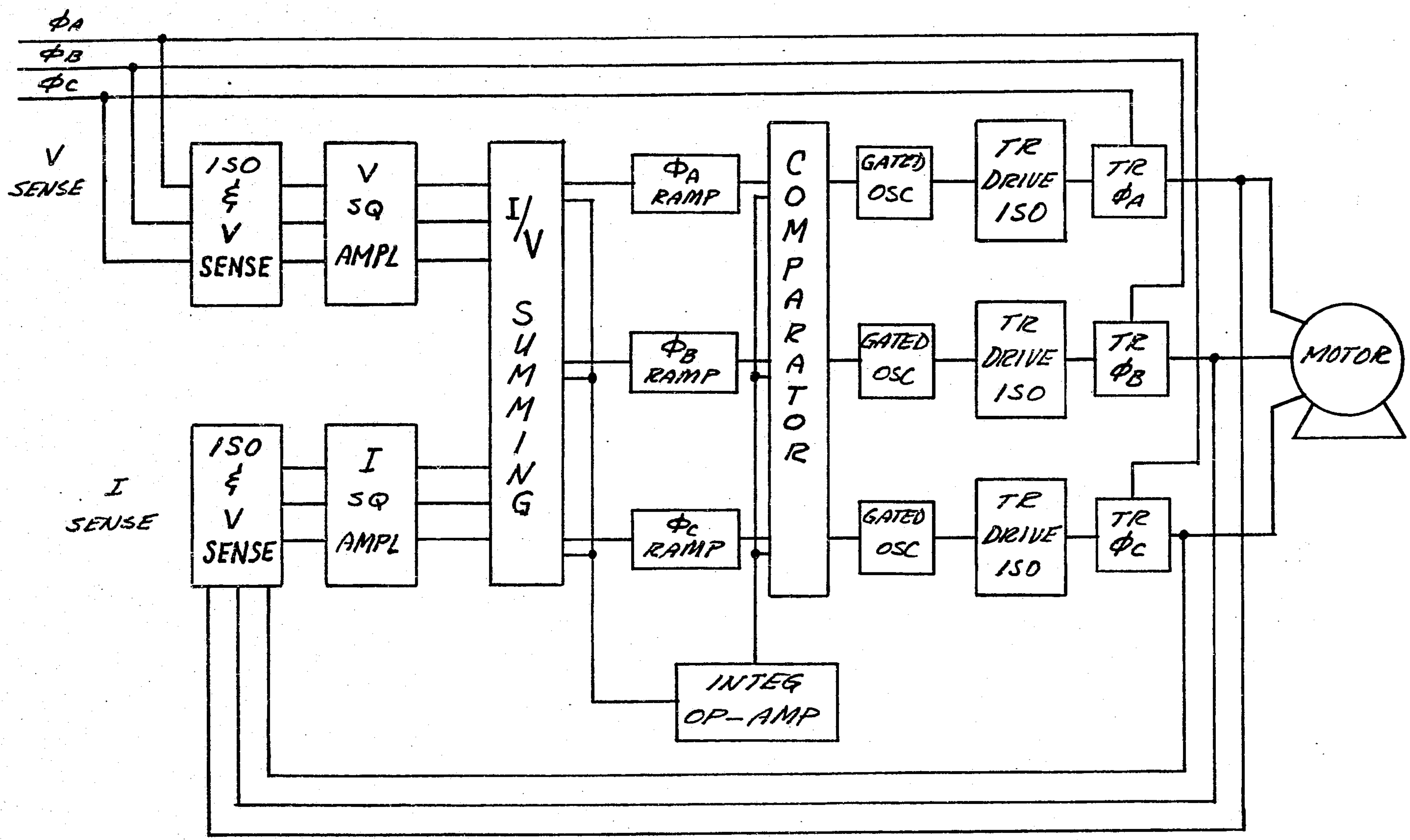

Figure 12 Block Diagram - Three-Phase Motor Power Controller

that is synchronized with each appropriate 60 Hz (50 Hz) line voltage. The intersection of the ramp with the error voltage is detected in three squaring amplifiers and the putputs provide the turn-ON of the triacs.

One of the intrinsic values of the technique employed is that all switching is done at zero (0) current. From the distribution line standpoint, this is extremely important. One can see that if, in a plant employing thousands of motors, switching were to occur during heavy current flow, electrical havoc would prevail on the distribution line. As it is, since all switching is done at zero (0) current, no transients are seen on the distribution line. Odd harmonics are, however, of concern. The purpose of the snubber circuit (RC network across the triacs) is to minimize these effects. The biggest concern involves the effect in on-line computers due to switching harmonics. Spectrum analysis has shown that the odd harmonics, due to triac switching, deteriorate in magnitude at a rate fast enough so that sensitive on-line equipment is not effected. IVECO has not seen, in any single instance, complaints of computer anamolies resulting from the motor power controller operation. All computers are designed with filtering sufficient to attenuate harmonic frequencies resulting from the normal ON-OFF switching of heavy equipment in factories (industries).

3.3 SALIENT TECHNICAL GUIDELINES OF THE MOTOR POWER CONTROLLERS

The electronic control design is only one of the major

technical hurdles which had to be accomplished. There are two (2) others: (a) triac current capability during start-up, and (b) thermal dissipation of current through the triacs.

3.3.1 Triac Current

Appendix H shows typical current capability curves of 15, 25, 30, 40, 60, and 80 ampere triacs. These curves show extremely high turn-ON characteristics of the triacs; however, such turn-ON characteristics are shortlived, i.e. one (1) cycle. It is impossible to start a motor in one cycle. Most motors require three to five seconds to reach operating speed. The rapid roll-off of the current capabilities of triacs require some knowledge of both the triac characteristic and motor start-up current requirements in order to assure that start-up can be achieved without loss of the triac switching elements. As an example, the current capability of a 40 amp (I_T) triac at 180 to 200 cycles (3 seconds) is about 100 amps. A 20-horsepower, 480-volt, motor typically exhibits a 108 amp constant current starting requirement to three seconds after turn-ON. This triac would fail turn-ON. Thus, a larger triac must be used or two triacs in parallel must be employed.

Tests have been made using parallel triacs for current sharing. Since it is impossible to have simultaneous turn-ON, investigations concerning the differences in turn-ON of two triacs in parallel, when gated-ON simultaneously, were made. The tests showed that both triacs could be expected to turn-ON (with

proper gate pulses) within a few microseconds of each other. In the example above, two 30A triacs would well survive turn-ON since each triac is capable of 300A at one-cycle (i.e., 8.33 ms). By the time the second triac came-ON, the first one would still be in its 300A surge current range. In terms of current sharing after turn-ON: tests show that without selection, the triacs will share at a rate no worse than 60-40.

3.3.2 Thermal Design

In terms of thermal capability, the design for thermally dissipating the heat caused by the current through the triac is not an overly complex problem; however, triacs will not survive more than 115°C at their substrate junctions, thus the guiding design parameter is to maintain junction temperatures below 115°C. When the motor is operating at full load, current flow through the triac is maximum. Example: Typically, a triac voltage drop is between 1.2 and 1.5 volts at full load current. A 40-amp triac, operating at 40 amps constant current would dissipate 48 watts at the junction. In a three-phase controller, the total heat generated at the triac junctions would be 144 watts total. The heat sink must dissipate heat generated in the switch, such that the junction would not exceed 115°C.

Table 3 is a heat sink chart showing all of the parameters of concern for three-phase controllers from 1 HP through 30 HP, in both 240 and 480 volts. Appendix J is the thermal analysis which

TABLE 3: HEATSINK CHART – 3Φ

Config.	I_{RMS} Per Leg	P_D/L	Triac Type (T_j °C Max)	# of Triacs P/L	I_{RMS} Per Triac	P_D/Triac	# of Triacs Per H.S.	P_D/H.S	Temp of H.S. (T_j)	R_{j-c} °C/W	Tot # H.S	Enclosure Size
1Hp 240VAC	2.96	3.9	SC240D4 (110°C)	1	2.96	3.9	3	11.7	174°F (89°C)	2.4	NONE	6"x8"x4"
5Hp 480VAC	7.4	5.0	T6420N (110°C)	1	7.4	5.0	3 (E103-4)	15	150°F (73°C)	1.0	1	6"x8"x4"
5Hp 240VAC	14.8	12.0	SC265D4 (115°C)	1	14.8	12.0	3 (E103-6)	36	176.5°F (98°C)	1.1	1	6"x8"x4"
10Hp 480VAC	13.0	9.5	T6420N (110°C)	1	13.0	9.5	3 (E103-6)	28.5	163.5°F (87.3°C)	1.0	1	6"x8"x4"
10Hp 240VAC	25.9	20	SC265D4 (115°C)	2	13.0	10	6 (E360-6)	60	178.5°F (96.3°C)	1.1	1	6"x8"x4"
20Hp 480VAC	25.9	24	T6420N (110°C)	1	25.9	24	3 (5305-8)	72	144°F (98.2°C)	1.0	1	8"x8"x4"
20Hp 240VAC	51.9	52	SC265D4 (115°C)	2	26	26	3 (5305-8)	78	147°F (102.8°C)	1.1	2	12"x15"x4"
30Hp 480VAC	38.9	32	T6420N (110°C)	2	19.5	16	6 (5305-7)	96	160.7°F (95.5°C)	1.1	1	8"x8"x4"
30Hp 240VAC	77.8	84	T8421D (110°C)	2	38.9	42	3 (5305-9)	126	164.6°F (99°C)	0.4	2	12"x15"x4"
1Hp 240VAC	2.96	3.9	SC240D4 (110°C)	1	2.96	3.9	3	11.7	174°F (89°C)	2.4	NONE	6"x8"x4"
5Hp 480VAC	7.4	11.1	T6420N (110°C)	1	7.4	11.1	3 (E103-4)	33.3	172°F (100°C)	1.0	1	6"x8"x4"
5Hp 240VAC	14.8	14	SC260D4 (115°C)	1	14.8	14	3 (E103-6)	42	187°F (113.°C)	1.55	1	6"x8"x4"
10Hp 480VAC	13.0	19.5	T6420N (110°C)	1	13.0	19.5	3 (E360-10)	58.5	153.5°F (107°C)	1.0	1	8"x10"x4"
10Hp 240VAC	25.9	20	SC265D4 (115°C)	2	13.0	10	6 (E360-6)	60	178.5°F (96.3°C)	1.1	1	6"x8"x4"
20Hp 480VAC	25.9	38.9	T6420N (110°C)	2	13.0	19.5	3 (E360-10)	58.5	153.5°F (107°C)	1.0	2	12"x15"x4"
20Hp 240VAC	51.9	54	SC265D4 (115°C)	2	26.0	26	3 (E360-10)	78	168°F (115°C)	1.1	2	12"x15"x4"
30Hp 480VAC	38.9	58.4	T6420N (110°C)	2	19.5	29.2	2 (E615-12)	58.4	126°F (110°C)	1.0	3	12"x15"x4"
30Hp 240VAC	77.8	116.7	T8420D (110°C)	2	38.9	58.4	2 (E615-12)	116.7	147°F (104°C)	0.4	3	12"x15"x4"

AMBIENT 100°F

provides the derivation for all of the data shown in Table 3. The criteria for Table 3 and Appendix J are ambient temperatures of 100°F. Appendix K provides heat sink data and derivation for an ambient of 150°F controllers designed for operation. They require internal blowers to move heat across the heat sinks.

3.4 ADDITIONAL SALENT TECHNICAL FEATURES OF THE MOTOR POWER CONTROLLER

Due to the nature and to the electronic design of the three-phase motor power controllers, they are a natural in terms of their ability to provide protection features for motors, under their control, not previously available. Conceivably, users could find value in the motor power controllers specifically for these features alone.

More and more motors are put on the line every year. This growing motor usage increases the risk of injury to plant personnel and increases the potential for greater downtime, higher motor costs, and fire damage caused by overheated and burned out motors. Conditions leading to motor overheating and burnout fall into six (6) major categories:

A. Source induced:

Phase failure, over and under current, phase sequence, and phase unbalance of incoming power decrease motor efficiency.

B. Load Induced:

Overload, jamming, underload, and long acceleration time raise or lower power demand from the motor, changing power used by the motor.

C. Application Induced:

High ON/OFF duty cycle, rapid reversing, and plug reversing cause repeated in-rush current levels that exceed full load current ratings, even though running current may be less than or equal to full-load current.

D. Load Wiring Induced:

Wire insulation failure and loose connections damage the controller which causes other problems, such as single-phasing, which damages the motor.

E. Motor Induced:

Insulation and bearing failures lead to excessive motor heating and burnout.

F. Environmentally Induced:

High ambient temperatures and contaminants increase motor temperature.

Motor protectors normally respond to one of two factors: (a) line current to the motor, or (b) motor temperature. Some protectors respond to both. For large motors (20 HP and up), current sensing is the preferred protection method. Most motor burnouts can be traced to excessive current surges.

The motor power controller uses current sensing as its primary mode of input data. Voltage sensing is done to derive the relationship to current. The controller electronics utilizes these two (2) parameters and generates some references of its own to complete the control process; therefore, the controller is a natural in terms of motor protection, since the controller monitors all three (3) current legs in a three-phase motor. Excessive current in any one phase can easily be detected. The controller monitors voltage in each leg, and therefore can detect a loss of phase. Also, low voltage can easily be determined.

IVECO Motor Power Controllers offer, as an option, a protection package that includes: Loss of Phase Detection, Low Voltage Threshold, and High Current Detection; any one of which will remove power to the motor. The controllers have been tested and can be equipped with added features, such as:

(a) Ramp start capabilities - This amounts to current limiting during start up, thereby minimizing excessive sudden energy requirements.

(b) Loss of phase protection - If power on one or two phases is lost, the controller can shut down the motor, thus protecting it from high torquing current on the remaining phases, possibly resulting in burnout.

(c) High current shutdown - Thermal shutdowns, a normal

feature of motors, are designed, not necessarily as motor protection, but rather to prevent fires. When a motor thermal cutout is activated, temperature is rising at an excessive rate and passes through the thermocouple activation point, i.e. it does not stop there. In other words, since temperature is still rising, further damage can occur to the motor even though thermal cutout occurs. The high current shutdown feature of the controller will protect the motor since detection is in milliseconds.

(d) Low voltage shutdown - During "brownouts", line voltage seriously drops and, in many cases, is low enough to cause heavy torquing and high current in the motor. Many motors are lost due to the thermal effects of this high current. The low voltage shutdown feature of the controller has the ability of pre-determining a minimum voltage of operation at which the motor is shut down. Actually, since the controller must turn triacs ON each one-half cycle, these triacs would not be turned ON if the line voltage dropped below the pre-determined value. Note that shutdown then, in the worst case, is no further away in time than approximately 8 milliseconds.

(e) Automatic recovery after shutdown - When all maligned parameters (above) return to normal, the controller automatically will restart the motor.

Figure 13 shows the circuit configuration for low-line voltage protection.

In the three-phase controller, the unregulated bus provides power to the oscillator buffer driving the triac gate-drive transformers. If the unregulated bus is not present, then no gate drive exists and the triacs are OFF, thus turning the motors OFF. The philosophy of the low-line protection circuit is to control the unregulated bus. When line voltage is above a pre-selected value, the op-amp provides a positive base voltage to an NPN switching transistor, thus permitting the unregulated bus circuit to pass. When the line voltage drops below the selected value, the op-amp output goes negative, thus turning the NPN transistor OFF. This, then, removes the unregulated bus from the triac gate drive, thus turning the triacs OFF, consequently shutting the motor down.

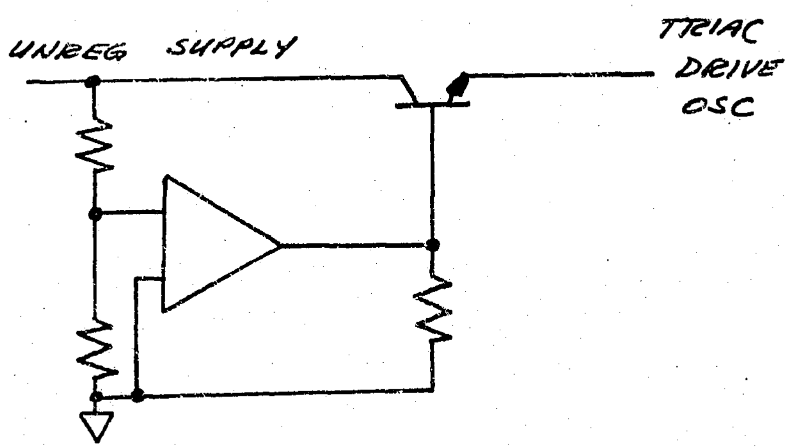

Figure 13

Low-Line Voltage Protection

The purpose of this circuit is to prevent a serious "brownout" from causing damage to motors which are under load, but starved for drive potential.

Figure 14 shows the loss of phase protection circuit configuration. Eventually, a signal from the three-phase voltages are brought to a three-input AND gate. The output provides positive base voltage to an NPN switching transistor, whereas before the unregulated bus current passes through the switching transistor. If any of the three-phase voltages is missing, the output of the AND gate goes to ground and base drive is removed from the switching transistor, causing removal of the unregulated bus to the triac gate drive buffers.

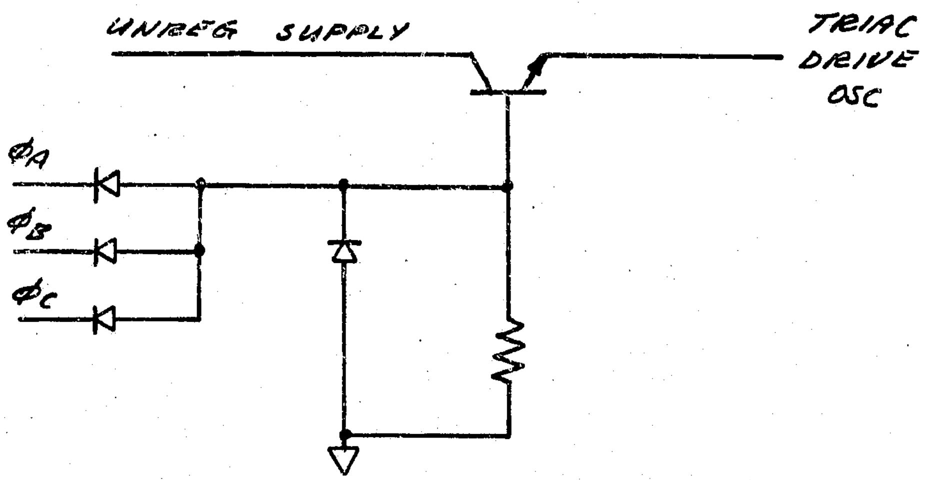

Figure 14

Loss of Phase Protection

As in the low-voltage protection philosophy, hi-current detection

is also based on a pre-selected threshold value, above which the controller removes power to the motor. Figure 15 shows the technique employed. Current is sensed in a power line, if it exceeds the pre-selected value, the unregulated voltage to the triac gate drives are removed, thus removing power to the motor.

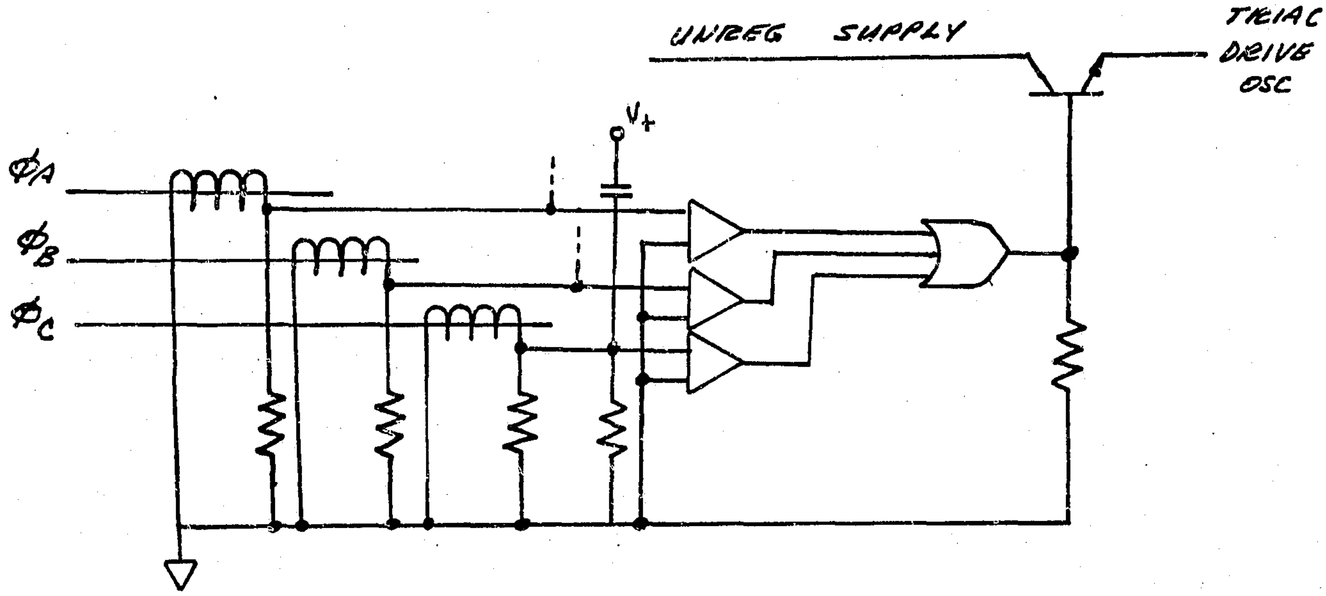

Figure 15 High Current Protection Circuit

3.5 DIRECT BENEFITS

The direct benefit, as a result of using motor power controllers, include five (5) monetary saving items:

(a) Reduced direct energy costs - Savings are represented in power reduction directly off of the kilowatt meter.

(b) Demand charges reduced - Overall power is reduced appreciably during demand power periods.

(c) Reduction of poor power factor penalties - In induction motors, a reduction in load results in deterioration of power factor. The controllers are designed to maintain power factor at or near full load capacity values. Thus, during on-load periods, there is a significant improvement in power factor.

(d) Longer motor life - A reduction in operating temperatures extend the life of the motor. Typically, motor life doubles for every 10° reduction in temperature.

(e) Lower air-conditioning costs - The industrial sites where there is a concentration of motors, a reduction in motor operating temperatures can reduce the thermal ambient. Typically, air-conditioning requirements can be reduced 0.25 kilowatts for every one kilowatt reduction of power otherwise dissipated in heat.

3.6 THE MOTOR POWER CONTROLLER VERSUS CAPACITORS

Often-asked questions are: Can the controllers be used with capacitor banks? Do they replace capacitors? Should they not be used with capacitors?

Capacitors are often employed in shunt configurations to compensate for inductive loads. One must remember that placement of capacitors across a power line to compensate for an inductive load will compensate for one (1) specific value of inductive reactance. If a specific load has a fixed non-varying value of

inductive reactance, a capacitor of equal capacitive reactance can be placed across the power line, resulting in a power factor of 1.0. If a given load has a varying inductive reactance, no one value of capacitor can compensate for the varying inductive reactance, therefore the user must try to determine the average value of inductive reactance in order to decide on what capacitor value to employ. All motors represent inductive reactance on a power line. If the motor load varies, inductive reactance also varies. No value of fixed capacitance will compensate for the inductive reactance; therefore, a choice must be made regarding the value of capacitive reactance to be employed.

In industry, where many motors are used, capacitors are placed at the power line where power is metered to the facility. The large quantity of motors are usually in varying degrees of load, still others are ON, and others are OFF. An average value of inductive reactance can be determined at the meter and a capacitor bank used to compensate for the average. This is the method presently employed in industry so as to maintain a high power factor. The technique assumes that <u>not</u> all motors will be at their worst inductive reactance value at any given time, but that some will be high, some low, and there is a given range of average power factor for which the capacitors can compensate. On the other hand, if a motor load is constant, use of capacitors is a good approach, since they can compensate for the fixed value of inductive reactance. Conversely, if the motor load varies, ideally one would like to have capacitive

reactance vary inversely.

The motor power controller is designed to hold power factor at or near that which is present at full load, no matter what the loading or the load profile on the motor is. Note that the controller does not make any significant power factor improvement at full load; therefore, at full load some value of inductive reactance exists, but that value of inductive reactance, using the motor power controller, would remain at or near the full load inductive reactance value. One could, therefore, choose a value of capacitance which would provide a capacitive reactance to compensate for the motor inductive reactance at full load and permit the controller to provide constant power factor during the dynamic low profile. In this manner, the highest value of power factor can be maintained.

What about cases where capacitor banks are already used in industry at the substation or at the meter. If a controller is employed on motors within the facility, what must be done about the capacitor bank. Oftentimes, industry indicates that by use of capacitor banks at their meter or substation, they can maintain power factor as high as 0.9. Motor power controllers on individual motors could bring this value even higher. If the controller compensation were to cause the line to result in a capacitive power factor, it would be a simple matter of removing capacitors at the meter or substation.

The most important point to make about the capacitors versus the

motor power controller is that the motor power controller can make a very significant reduction in current flow through the motor; therefore, significantly reducing I^2R losses. These losses result directly in heat.

In addition, the reduction of current through the motor also reduces I^2R losses through all of the electrical wiring from the meter or substation to the motor.

The conclusion is that capacitors would not be done away with, but rather be used in conjunction with the controller so as to improve overall industrial power factor. Such improvements result directly in energy conservation and can reduce or eliminate power factor penalties where applied.

3.7 SUDDEN LOAD CHANGES

The attachments to the Work Statement included drawings as follows:

- o Attachment 2 - Electronic Power Factor Controller Schematic For a Three-Phase Motor
- o Attachment 3 - Drawing No. 50M25606 For a Single-Phase Motor
- o Attachment 4 - Drawing No. 50M25607 For a Single-Phase Motor

Utilization of the circuitry shown in any of these schematics demonstrates that a sudden load, if heavy enough, can stall out the motor. A sudden load of any magnitude does cause a decrease in speed and motor torquing, causing a sudden rise in current which, if significant enough, and often enough, could cancel the savings during normal operation.

Figure 16 shows a circuit configuration which, when implemented into the control system electronics, will eliminate the previously described effects of a sudden load. This circuit is referred to as a "bump" load circuit. In effect, when a motor is subjected to a sudden load, the integrator op-amp, which normally would decrease in output voltage signal, is pulsed coupled to the "bump" load circuit which feeds back and inhibits a signal to the op-amp, thus driving the triacs full ON. When the "bump" load circuit recovers, the controller resumes normal operation.

3.8 NEUTRAL CONNECTION

In the field, there are often found two (2) types of three-phase motors. Those known as "delta" wound, and those known as "wye" wound. "Wye" wound motors have a neutral connection at the intercept of the three (3) legs of the "Y". In "Y" wound motors, the neutral connection is not readily available. Worse yet, such a connection would require that the controller be placed physically close to the motor. This is not necessarily desirable. One would prefer being able to locate the controller anywhere on the power line, preferably near a junction box or near the breakers.

The only real need for obtaining a neutral connection is to maintain phase sequencing and to assure proper time measurements between phases. The IVECO design is one that can be used on either "delta" or "wye"-wound motors and does not require a neutral connection. The neutral is internally derived, and phase relationships are thereby maintained. IVECO refers to

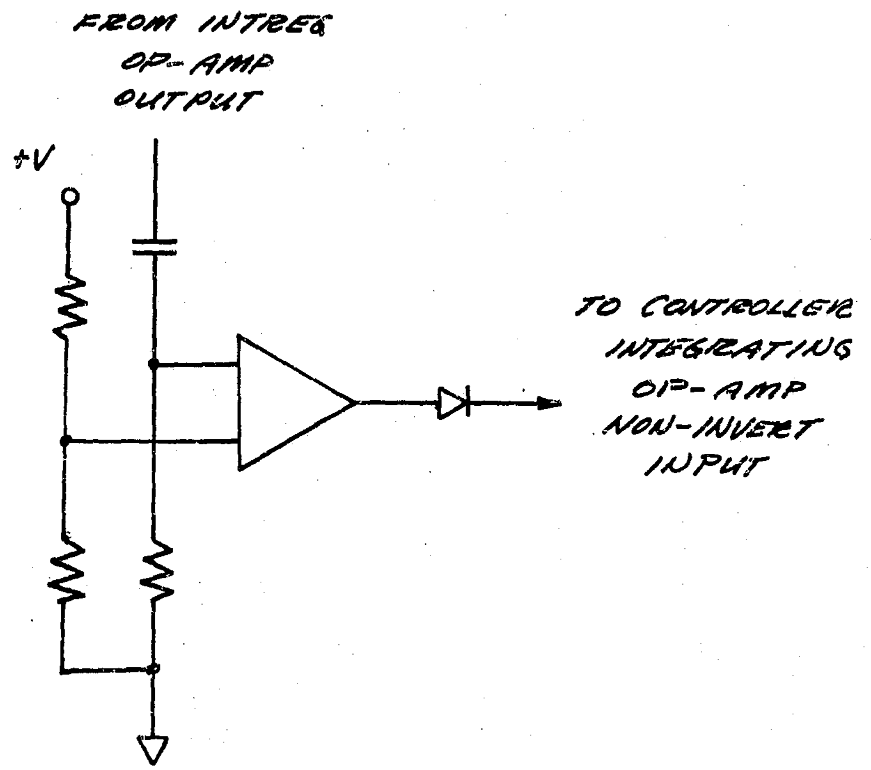

Figure 16 "Bump" Circuit for 1Ø & 3Ø Controllers

this technique as "phantom neutral", which is an IVECO proprietary design.

3.9 COST EFFECTIVENESS-AIR CONDITIONING

In applications such as the garment industry where a large number of motors are confined to a single area such as a large sewing room, the I^2R generated in the motors accumulatively amounts to a significant heat source, which in the summertime, must be compensated for through the use of air conditioning. One can go through a rigorous calculation of the amount of heat in BTU that is generated, but such a calculation would be negated because of the large number of assumptions necessary. The best approximation to the cost effectiveness power factor control on these motors in terms of air conditioning reduction comes directly from the garment industry itself. A thumb rule often applied is the following: For every kilowatt of power reduced which is generated through I^2R losses, one-quarter kilowatt of air conditioning can be eliminated. This thumb rule is employed in factories where more than 25 motors in any single area (room) are employed.

3.10 PAYOUT

What single factor would justify the use of the motor power controller by end users. A rule of thumb widely used in industry could be the guiding parameter in terms of an important single factor justification. "A capital investment is justified if that capital investment can be paid for by its dollar savings in two (2) years". The common term is "payout". This same

definition could also be applied to users of the power factor controller in residential applications. Payout is calculated as the sum of five factors.

The five factors are:

(a) Direct kilowatts saving as shown on the watt meter.

(b) Reduction in demand charges.

(c) Improvement in power factor at reduced loads.

(d) Motor longevity.

(e) Reduced air-conditioning requirements.

The savings resulting from direct kilowatts reduction is shown in equation 2:

$$\text{Eq.2:}\ (\text{Hp})\ \frac{(0.746\text{kW})}{\text{Hp}}\left(\frac{\$}{\text{kWHr}}\right)\left(\frac{\text{Hr}}{\text{Yr}}\right)(\%\ \text{Savings})\left(\frac{1}{\text{eff}}\right) = \$/\text{yr. saved}$$

The first two terms convert horsepower to kilowatts. The third term is the average electric utility rate. The fourth term is the number of hours the subject motor is operated in a year. The fifth term is the percentage savings, either expected or measured. The last term is the motor efficiency.

For purposes of estimating the effects of the other four factors, the following may be used:

(a) Savings in demand charges; add half again the savings calculated in equation 2.

(b) Savings in poor power factor penalties; add five percent of the savings calculated in equation 2.

(c) Savings due to air-conditioning reduction; add 25% of the savings calculated in equation 2.

(d) For motor longevity, assume an extension of 50%.

If the cost of the motor power controller is less than, or equal to, the payout required, then its use is justified. Note that payout is a function of horsepower and percentage savings where percentage savings itself is a function of the load profile. Load profile is defined as the mechanical loading (e.g., the electrical power demand) during one (1) complete cycle of motor load sequence.

3.11 LARGE-SCALE APPLICATIONS OF THE MOTOR POWER CONTROLLER

There are any number of large-scale applications for the motor power controller. Tests have been run on elevators, machine tools, pumps of various sorts, air-conditioners, etc. Any one of these applications could be classified as large-scale as defined by the NASA contract (i.e., 1,000 or more). Figure 8 of this report shows estimated motor population and electrical energy consumption by user category. This Figure is an excerpt from a U.S. Department of Energy Report No. DOE/TIC-11339. The Figure shows motor applications in various horsepower ranges by user category and SIC (Standard Industrial Code). The Figure shows, not only large-scale applications, but the number of hours per year of motor use. It is the combination of large-scale applications, as defined by NASA, and average use per year that is deemed important. Two thousand hours a year is typically a five-day, eight-hour week,

where 3,000 hours would be a twelve-hour day. Appendix E of this report shows Standard Industrial Codes applicable to Figure 8.

Large-scale applications can easily be seen in Figure 8 by observing the average use hours for any of the horsepower ranges. There are far too many to be singled out here. IVECO has, however, made tests using the motor power controller on applications such as air compressors, sewing machines, electric vehicle drive motors, plastic grinders, air handlers, elevators, vacuum pumps, air-conditioning blowers, and machine tools. Section 4.0 of this report encompasses test data, results of the tests, tests in progress, and future tests which will become a part of this report.

Appendix L is a derivation of potential energy savings for three-phase motors in the 1, 5, 20, 50, and 125 horsepower ranges, and by average annual use from 1,000 hours through 3,000 hours per year. Average estimated savings are also shown.

The data is derived from the potential energy conservation using the motor power controller of Table 2.

3.12 USE OF SCR'S

Development testing has shown that triacs cannot be used above 20 HP, 240V, three-phase and 30 HP, 480V, three-phase applications. The maximum extent of the electrical capability of triacs is met at these ranges. For motor power controllers operating with

motors larger than the above, SCR's as the switching element, must be used. From the standpoint of the control electronics, the only impact is assuring proper gate drive for the SCR's. The only other impact is the obvious mechanical method for thermal cooling.

3.13 COST/PRICE

Table 4 shows a typical price table for motor power controllers, both single and three-phase through 20 HP.

IVECO's philosophy, because of the extreme quantities of controllers required, is to market through distributors and dealers; therefore, the price table provides typical factory prices for a final selling price to which has been added distributor and dealer markups. Appendix M provides detailed cost-price breakdowns and "macro-material's" list.

All prices shown as based on quantities of 30,000 to 50,000 units.

(See following page for Table 4)

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TABLE 4

TYPICAL PRICE TABLE

1Ø, 120VAC, 60 Hz

HP	Factory Price	Distributor	Dealer	Selling Price
1	$ 51.62	20%	35%	$ 83.62
3	55.14	20%	35%	89.33
5	58.65	20%	35%	95.00

3Ø, 240VAC, 60 Hz

HP	Factory Price	Distributor	Dealer	Selling Price
1	$120.80	20.0%	35%	$195.70
5	147.65	22.5%	40%	253.22
10	173.10	22.5%	40%	296.87
20	238.60	22.5%	40%	409.20

3Ø, 480VAC, 60 Hz

HP	Factory Price	Distributor	Dealer	Selling Price
1	$125.90	20.0%	35%	$203.96
5	153.40	22.5%	40%	262.40
10	180.30	22.5%	40%	309.21
20	251.10	22.5%	40%	430.64

3.14 MARKETING PLANNING

In order to secure orders for the single and three-phase motor power controllers, a specific marketing strategy was established. The strategy was initiated and carried on simultaneously with the development program.

The motor power controllers (MPC) productwise, fall into the high quantity-medium price category, and as such, fit the mold for distribution methods of selling. This has the added advantage of maintaining smooth production cycles.

IVECO's marketing philosophy involves the establishment of up to ten (10) distribution centers located throughout the United States. Each center then employs up to 100 dealerships sized in accordance with the markets available in those areas.

IVECO believes that the motor power controller is an extremely important and valuable invention. The motor power controller potential is enormous and can eventually represent a very great energy savings. Care, however, must be taken to ensure that IVECO does not overextend itself in terms of trying to cover an excessively wide range of motor applications and markets.

3.14.1 Product Categorization

Motors employed in industry cover a very side range of horsepower capability. It is obviously not practical from the monetary/ payout standpoint to develop an all-encompassing controller. It would be price prohibitive to apply a motor power controller capable of operating at 20 HP to a motor application of 1 HP. Therefore, it is necessary to break down this wide range into a series of smaller horsepower ranges. The controller is then modeled to suit the smaller range categories. At the present time, several horsepower ranges are designated. Each range is covered by a separate version of the EY1021 or EY1027 series

controllers as follows: The IVECO controllers are sized via two (2) basic motor parameters: (a) the motor horsepower, and (b) the motor voltage. The horsepower determines the triac size. The voltage determines the size of the input transformer.

<u>Single-phase Motor Voltage Controllers:</u>

Example: EY1021 C/B

Describes Horsepower Rating

Describes Input Voltage and Frequency

Horsepower		Voltage	
"A"	thru 1 HP	"A"	115 VAC, 60 Hz
"B"	thru $1\frac{1}{2}$HP	"B"	220 VAC, 60 Hz
"C"	thru 3 HP	"C"	115 VAC, 50 Hz
"D"	thru 5 HP	"D"	220 VAC, 50 Hz
		"E"	Custom, Specify

<u>Three-phase Motor Voltage Controllers:</u>

Example: EY1027 E/C

Describes Horsepower Rating

Describes Input Voltage and Frequency

"A"	thru 1 HP	"A"	115/200 VAC, 60 Hz
"B"	thru 3 HP	"B"	230/400 VAC, 60 Hz
"C"	thru 5 HP	"C"	460/800 VAC, 60 Hz
"D"	thru $7\frac{1}{2}$HP	"D"	115/200 VAC, 50 Hz
"E"	thru 10HP	"E"	230/400 VAC, 50 Hz
"F"	thru 15HP	"F"	460/800 VAC, 50 Hz
"G"	thru 20HP	"G"	Custom, Specify
"H"	thru 30HP		

3.14.2 Strategy

The basis for this marketing plan assumes a two-step distribution system on a national basis.

The United States is divided into seven (7) major markets. Each of these markets are given a priority target value which establishes their order of importance and scheduling for penetration. It is critical that flexibility be maintained regarding these targets so that reaction to changing market conditions be quick and concise, if necessary. Penetration into each marketing area is governed by total production capability.

Seven (7) Key Market areas have been established and are shown in Figure 17; they include:

1. West
2. Northeast
3. Southeast
4. North Central
5. Central
6. South
7. Metro - East

Headquarter cities for the Key Market Areas are:

West	Los Angeles - San Francisco
North East	Hartford - Boston
South East	Atlanta - Miami
North Central	Chicago
Central	Kansas City - St. Louis
South	New Orleans - Nashville - Dallas
Metro - East	New York - Philadelphia

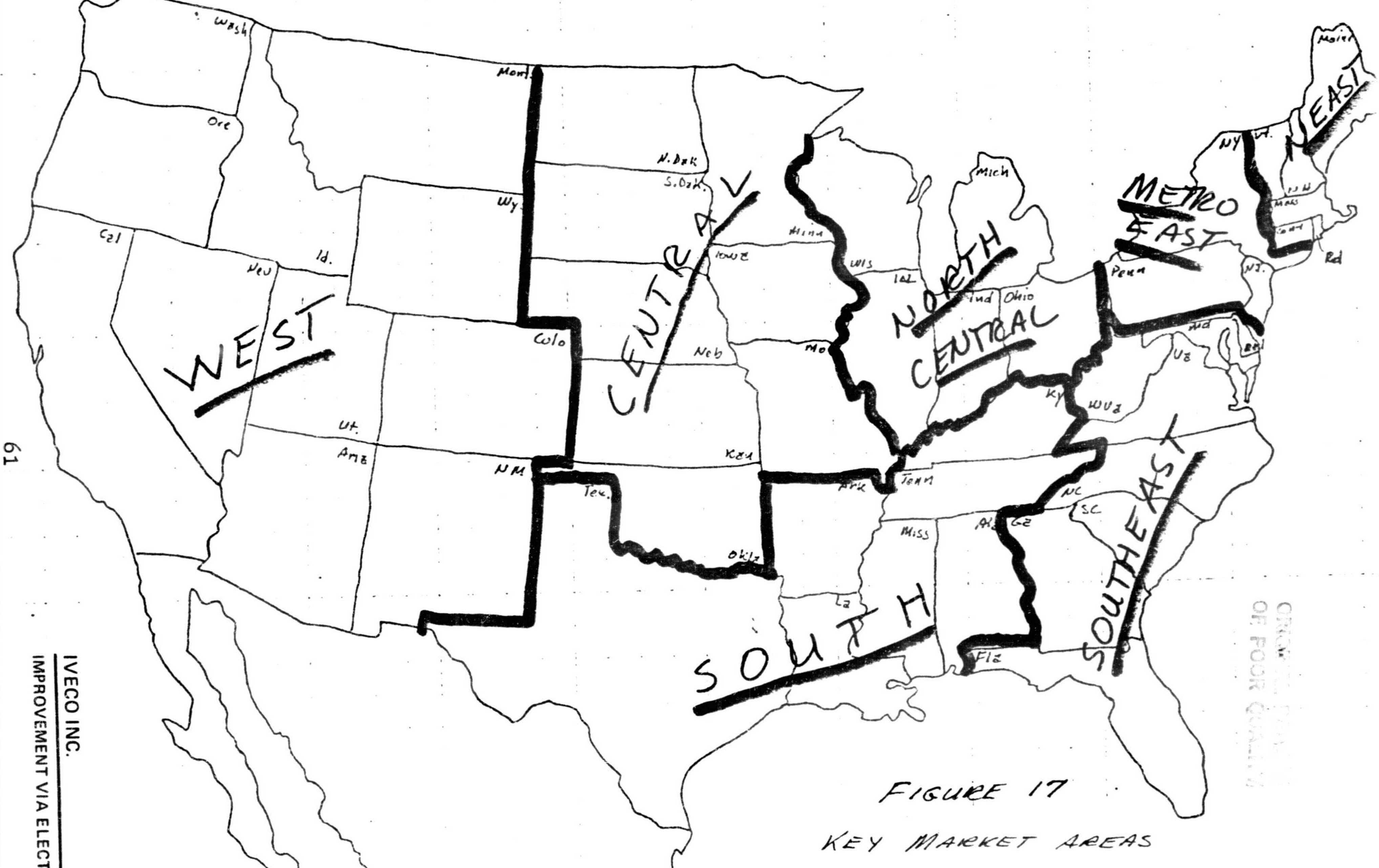


FIGURE 17

KEY MARKET AREAS

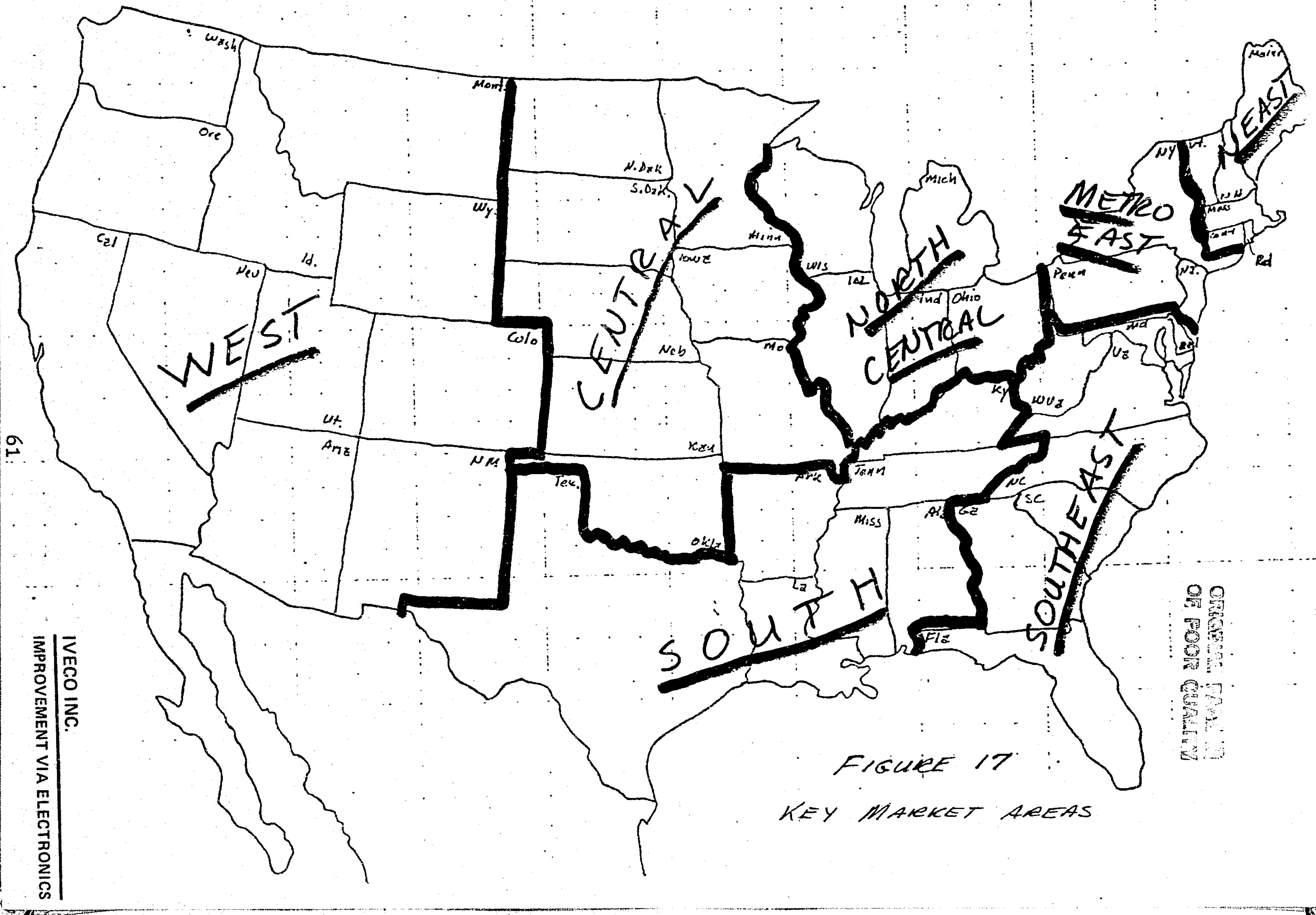


FIGURE 17

KEY MARKET AREAS

These are suggested only and when desirable qualified distributors are available. It is possible that their headquarter cities may differ with the suggested location. Obviously, an adjustment would be made.

Table 5 provides a listing of areas by states.

TABLE 5

AREAS BY STATES

MARKET AREA	AREA
West	Washington, Oregon, Idaho, Montana, Wyoming, California, Nevada, Utah, Colorado, Arizona, New Mexico, Alaska, Hawaii
North East	Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island
South East	West Virginia, North Carolina, Virginia, South Carolina, Georgia, Florida, Maryland, Delaware, Washington, D.C.
North Central	Michigan, Wisconsin, Illinois, Indiana, Ohio
Central	North Dakota, Minnesota, South Dakota, Iowa, Nebraska, Kansas, Missouri, Oklahoma
South	Texas, Kentucky, Tennessee, Arkansas, Louisiana, Mississippi, Alabama
Metro - East	New York, New Jersey, Pennsylvania

Two-step distribution demands a close working relationship between the factory and distributors and on a periodic basis, certain dealers for the company. The company attitude is always: '<u>sell through</u>" and <u>not</u> "<u>sell to</u>".

Product problems if any, including pricing, and application of product is an open line of communication between Factory - Distributor - Dealer.

Marketing education techniques are vital to any "<u>Sell Through</u>" program. IVECO's responsibility to the distributor - dealer organization ends only when the product is sold.

Product benefits must be incorporated into a major thrust at the <u>Dealer level</u>. Working through distributors, it must be made certain that IVECO's story is properly and frequently told. Dealer training must become IVECO's responsibility until it is certain that the distribution pattern is established on a market basis, and is fully qualified to handle all aspects of our marketing needs.

Starting in the West is highly logical since freight problems, logistics, marketing help, and assistance are surely easier to handle without high travel costs and/or on a long distance basis. California - properly handled, could well take most of the first years production and provide some first-hand knowledge of potential problem areas, as well as opportunities. A well-controlled and orderly growth pattern from that beginning

is highly advisable, and with proper targeting will assure success.

The goal in the West is the complete marketing of the eleven (11) Western states.

3.14.3 Distributor Profile

Before enlisting a distributor organization, it is necessary that his philosophies, methods and ethics be consistant with the Factory. The following describes the IVECO distributor profile:

(a) Proven ability to take new and/or innovative product to market.

(b) Warehouse or stocking capability.

(c) Sales force calling on stratified dealer structure.

(d) Strong financial capability.

(e) Ability to lead - direct sales force to major industrial and commercial users.

(f) Willingness to "go direct" if necessary to insure companies market share.

(g) Continuity in market place - or track record if a new operation.

3.14.4 Product Warranty

A clear, concise, written warranty, spelling out any limitations is essential.

3.14.5 Packaging

Packing and shipping procedures should be reviewed periodically to be certain that we are meeting the <u>needs</u> of the customer.

3.14.6 Advertising

Initial start-up advertising plans at the distributor level should be reviewed by the factory until appropriate guide lines are agreed upon. Overstating our products capability, or misleading anyone, however unintentional, must be avoided.

3.14.7 Distributor Contracts

Distributor Contracts should be clearly written and spelled out in understandable terms, describing the responsibilities of the distributor as well as the manufacturer.

IVECO assumes the manufacturer's position at all times. The fact that the product is contracted for assembly has no bearing on the IVECO - Distributor relationship. It is not likely that all distributors have the same distribution background or marketing approach. With that in mind, IVECO's strategy, with certain distributors, may have to vary with their marketing approach and expertise. Once established, and once IVECO has identified distribution needs in the market place, then IVECO can guide distribution to new markets and opportunities.

Distributors must be assigned specific quotas and measured on a timely basis as to attaining established goals.

4.0 TEST DATA/REPORTS

During the course of this contract, many technical problems were encountered in the field. The technology of the motor power controllers can be considered new and, as a result, many implications of their application were unknown prior to use. It was found that many motors, in their present operating applications, can be classified as unstable.

The electronic nature of the controller versus the electrical nature of the motor, compounded this problem due to the differences in response time of the two devices. Application for test data collection was hampered by technical anomalies encountered during the test period of this contract. For this reason, two time extensions were sought and granted. Up to the final month of the contract period, some instability was still being seen in the field, consequently, not all tests have been completed to the satisfaction of IVECO. Such tests will be completed at IVECO's expense and will be submitted as an addendum to this report.

Table 6 provides a summary of the results of tests successfully completed. Most of the tests indicate greater savings than was anticipated. The only explanation for some of the surprising results is that theoretically all of the I^2R loss savings were not anticipated. Also, there is an effect on efficiency which has not been included in the calculation.

The following is a list and description of tests yet to be completed and will be provided in the aforementioned addendum:

(A)	Sandia Labs, Albuquerque, New Mexico	(1) Vacuum Pump, 3 HP, 240VAC (2) Lathe, 10 HO, 480VAC, 3Ø
(B)	Southern California Edison San Bernardino, California	(1) Air Conditioner Fan 10 HP, 480VAC, 3Ø
(C)	Washington Metro Rapid Transit Authority Washington, D.C.	(1) Escalator, 10 HP, 480VAC, 3Ø
(D)	Goodrich (Martha Mills) Griffin, Georgia	(1) Twister 15 HP, 480VAC, 3Ø
(E)	SPEC Tool Company Pico Rivera, California	(1) Air Compressor 25 HP, 480VAC, 3Ø

TABLE 6

MOTOR POWER CONTROLLER ENERGY SAVINGS

THREE-PHASE AC INDUCTION MOTORS

ITEM	USER	MOTOR DESCRIP.	O/P SAVED	APPLICATION
1	SANTA ANA COUNTY, CA	10 HP, 480VAC, 3Ø	16%	Air Compressor
2	PIERCE COLLEGE Pasadena, CA	5 HP, 230VAC, 3Ø	43%	Air Handler
3	NEWELL PLASTICS Glendale, CA	3 HP, 230VAC, 3Ø	40%	Plastics Grinder
4	DISNEYLAND Anaheim, CA	3 HP, 480VAC, 3Ø	59% Uphill 44% Downhill	People Mover
5	BLUE BELL Atlanta, GA	½ HP, 208VAC, 3Ø	30% Avg.	Industrial Sewing Machine
6	DIXIE YARN Atlanta, GA	½ HP, 208VAC, 3Ø	31% Avg.	Industrial Sewing Machine

SINGLE-PHASE AC INDUCTION MOTORS

ITEM	USER	MOTOR DESCRIP.	O/P SAVED	APPLICATION
1	HOME APPLIANCE	½ HP, 115VAC, 1Ø	35%	Evaporative Cooler
2	HOME APPLIANCE	½ HP, 115VAC, 1Ø	16.5%	Central Heating Blower Fan
3	DISNEYLAND Anaheim, CA	½ HP, 230VAC, 1Ø	41%	Vehicle Wheel Drive
4	SANDIA LABS Albuquerque, N.M.	1 HP and less 115VAC & 230VAC, 1Ø	25%	

APPENDIX A

STATEMENT OF WORK

A. Technical Requirements:

1. Perform engineering development on the existing circuitry for both single and three-phase motors and recommend modifications which will improve the performance, producibility, and/or applicability of the circuit (e.g., investigate a method of eliminating the need to bring out the neutral of a wye-connected three-phase motor). These modifications will be implemented upon approval of the COR.

2. Determine the ability of the circuit and motor to respond to sudden changes in loading. If it is determined that a given type of loading results in instabilities, recommendations shall be made for modification which eliminates the problem. These modifications will be made upon approval of the COR.

3. Study various types of motor applications and identify those applications where this controller would be beneficial.

4. Identify and/or define a large scale application (i.e., 1,000 or more) of motors with a cyclic load and determine the cost effectiveness of applying the motor controller. This shall be done for both a single-phase application and a three-phase application.

5. Study and provide a discussion concerning the potential this controller has for reducing the costs that users of motors presently pay for having a poor power factor or for

uneconomical electrical demand.

6. Study the potential this controller might have for minimizing the need for power factor correction capacitors or synchronous motors in a typical application. If it is found that the potential exists, take the example in paragraph "4" above and determine by analysis the benefits.

7. Study and provide a discussion on whether the cost effectiveness of this controller can be enhanced in certain applications by serving also as the power contactor for the motor.

8. Study and provide a discussion on whether the cost effectiveness of the controller (with modifications) can be enhanced by serving as an inrush current limiter in larger motors.

9. Cost effectiveness studies shall take into consideration the reduction in air conditioning load through reduction in heat generated by the electric motors.

10. High density packaging is not required. A packaging volume for the single-phase controller of 35-40 cubic inches (approx. 6" x 4" x 1½") and 50-60 cubic inches for the three-phase controller will be acceptable.

11. Provide a cost estimate for 1 H.P. single-phase motor controllers based on production rates of 10,000, 20,000, and 30,000 units per month. Repeat this cost estimate for 3 H.P. three-phase controllers. The contractor shall estimate the cost variance with motor horsepower for the two types of controllers.

12. The contractor shall have the capability to manufacture 30,000 controllers per month.

13. Deliverable end items under the terms of this contract shall be 18 packaged single-phase controllers, which accommodate up to 5 horsepower and 240 volts, and 6 packaged three-phase controllers, which accommodate up to 10 horsepower and 440 volts, plus the written discussions and reports called for.

14. The first two single-phase controllers and the first two three-phase controllers complete will be furnished to MSFC.

15. Details of the circuitry are given in the attachment to the statement of work. (Attachment 1)

16. After completion of this contract effort, the disposition of the 10 controllers will be at the discretion of the prime contractor.

B. <u>General Requirements</u>:

1. The contractor will select seven (7) separate industrial or public sector organizations that will agree to have these controllers installed and tested for a period of time deemed necessary to demonstrate the effectiveness of the controller. Three (3) of these selected sites will have controller installed on single-phase motors, and the other four (4) sites will have the controller installed on three-phase motors. One single site may be utilized for testing both type controllers.

2. The contractor shall provide the engineering services required to install, monitor, and maintain the controllers

at all sites, and to collect and record the appropriate operational test data.

3. The contractor shall propose to NASA a cost-sharing plan which will clearly define all resources the contractor proposes to contribute to this effort. This plan is required in order to determine the desire and interest of the contractor in commercialization of this Power Factor Controller.

4. The contractor shall provide a marketing/commercialization plan.

5. User safety shall be considered in the design and packaging of the units.

NOTE: The following attachments are furnished for information only:

Attachment 2 - Electronic Power Factor Controller Schematic for a Three Phase Motor

Attachment 3 - Drawing Number 50M25606 for a Single Phase Motor

Attachment 4 - Drawing Number 50M25607 for a Single Phase Motor

APPENDIX B

REPORTS

A. Progress Report

During the period of this contract, the contractor shall submit a monthly progress report. This report shall be postmarked on or before the 19th of the month succeeding the period. This report shall be of brief narrative letter type and shall include the following:

1. A brief quantitative description of the work performed during the period and a discussion of the work to be performed during the next reporting period.

2. A discussion of any current problems which may impede performance, impact program schedule, and cost. Indicate what corrective action is being taken.

3. In addition, the following shall be furnished:

a. Total cummulative costs incurred as of the report date.

b. Estimate of cost to complete contract.

c. Estimated percentage of physical completion of contract.

d. Statement relating the cummulative costs to the percentage of physical completion with explanation of any significant variance.

B. Final Report

The contractor shall submit a final report which documents and summarizes the results of the entire contract work, including

recommendations and conclusions based on the experience and results obtained. The final report shall include, as applicable, tables, graphs, diagrams, sketches, curves, procedures, photographs, test data and drawings in sufficient detail to comprehensively explain the results achieved under the contract. The contractor shall submit two (2) draft copies of this report to the Contracting Officer's Representative (COR) for approval prior to final printing and distribution. The report will contain all site test data for the packaged single-phase and three-phase ccontrollers and include type of motors used in test demonstration activity.

C. Reports Distribution

Copies of reports, other than those with specific addresses, shall be distributed to National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812, to the codes and in the quantities indicated below. A copy of the transmittal letter showing distribution of the reports shall be furnished to AP28H.

Codes	Monthly	Final Draft	Final Approved	pDrawings & Specifications
AP28H	1	0	1	0
AT01	2	0	2	0
EC24	4	2	4	1 Reproduced
EM63-09	1	0	1	0
CC01	1	0	1	0
NASA Headquarters/Washington				
EPU-6/R. Gilbert	1	0	1	0
ETU-6/L. Mogavero	1	0	1	0

APPENDIX C

UL TECHNICAL SUBMITTAL

TECHNICAL DESCRIPTION

MODEL EY 1021

MOTOR POWER CONTROLLER

(SINGLE PHASE)

REGISTERED PROFESSIONAL ENGINEER
CONTROL SYSTEMS
STATE OF CALIFORNIA

IVECO, INC.

5762 Research Dr.

Huntington Beach, CA.

92649

(714) 891-9922

TABLE OF CONTENTS

LIST OF FIGURES

I INTRODUCTION

The purpose of the Motor Power Controller (also known as Power Factor Controller) is to improve power factor and reduce power dissipation in induction motors operating below full load. The Motor Power Controller is capable of raising power factors from 0.2 to 0.8 and results in energy savings as shown in figure 001.

II GENERAL DESCRIPTION (Refer to figure 002).

Power losses are reduced by sensing the phase lag between the motor voltage and current. This information is fed to the electronic controller which forces the motor to run at a constant predetermined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (i.e. triac or the equivalent) which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the triac remains ON until the current goes through zero. Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to the motor, the gate is triggered at a given point during the cycle, and the device switches OFF as the current goes through zero.

III DETAIL TECHNICAL DESCRIPTION

The reactive volt-amps of an induction motor is high when the motor is unloaded or partially loaded. Some motors tested showed unloaded current to be about 90 percent of the rated load current. These currents cause heat losses in the motor.

Since the current remains high in an unloaded motor, the phase between the voltage and current shifts with load. Typically, the current may lag the voltage 80 degrees in an unloaded motor and 30 degrees when loaded. Figure 003 shows how the power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference between the two produces an error signal which biases a ramp voltage that is in sync with the 60 hertz line voltage. The intersection of the ramp and the error voltages is detected by a squaring amplifier whose output provides the time for turning-ON a triac (or SCR's) in the motor line.

Thus, the ON time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the timing diagram of figure 004.

III DETAIL TECHNICAL DESCRIPTION (con't)

The phase angle shown as "θ" in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

When the circuit is in control of the motor current, voltage is applied to the motor for a portion of each positive and each negative half cycle of line voltage by means of the solid-state switch (triac) as seen in the timing diagram.

When the triac switches ON, rapid rise of the current is prohibited by the inductance of the windings. The current rises, reaches a peak, and then follows the voltage down as it approaches zero, but with a finite lag. Although the firing voltage to the triac goes to zero when the line voltage goes through zero, the triac inherently will remain ON until the current goes through zero. This is shown by the motor voltage waveform.

The phase lag between voltage and current is indicated by "θ" in the timing diagram. This is the parameter which is to be measured and controlled. The line voltage and its inverse are squared by squaring amplifiers as indicated by E and $\overline{E}$ in the timing diagram. Each current pulse is squared by similar amplifiers as indicated by I and I'. By "AND'ing" $\overline{E}$ with I, and E with I' and then "OR'ing"

the two, a pulse train is produced which has a pulse width proportional to the phase angle between voltage and current. When acted on by a low pass filter, the dc or average value of this voltage will be proportional to the phase angle. This voltage is summed with a command voltage from P1 (Electrical Block Diagram) which is indicative of a desired phase angle. The difference of the two is the system error voltage. This error is compared with a ramp which is synchronized with the zero crossings of the line voltage. The intersection of the sloped portion of the ramp and the error voltage are detected by the comparator Q2 and form the turn ON pulse for the triac.

As the load on the motor is decreased, the slight change in phase angle causes the error to drop and intersect the ramp at a lower point. This moves the firing pulse to the right, along the sine-wave, causing the triac to turn ON for a shorter duration, lowering the applied voltage. Conversely, an increase in load will cause the firing angle to move to the left and apply more voltage to the motor. Thus, a phase angle is commanded and the high gain of the feedback loop will vary the applied voltage to force the motor to operate at the desired phase angle regardless of load. Since the current is never higher than that required for a given load, motor losses are minimized.

III DETAIL TECHNICAL DESCRIPTION (con't)

A detailed electrical schematic of the EY1021 Motor Power Controller is shown in figure 005. Resistor R 8 and capacitor C 4 are used to reduce the EMI and RFI effects of the triac (or SCR) switching.

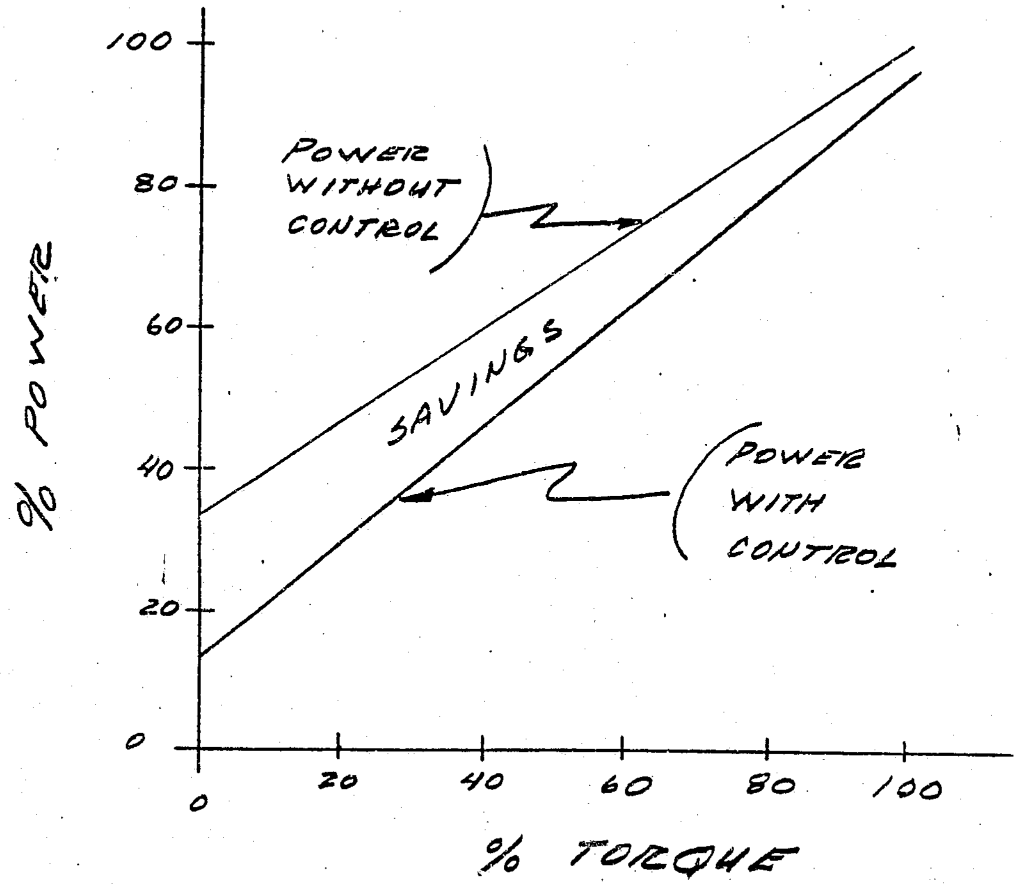
The difference in unit make-up for various horsepower involves changing triacs to accomodate larger current values and apply outside heat sinks for three-horsepower (and up) 115 VAC units as well as five-horsepower (and up) 120 VAC units. A chart showing triac vs horsepower is provided in Appendix B.

Appendix C is a copy of the patent covering the Power Factor Controller (Patent Number 4,052,648).

IV MODEL EY1021 HARDWARE REVISION

IVECO intends to modify the single phase Motor Power Controller by replacing the printed circuit board and eliminating the transformer. The existing hardware is in accordance with the schematic shown in figure 005 A & B and Parts list number PL 1021-006-00038A. The revised hardware is in accordance with the schematic shown in figure 006 and Parts list number PL 1021-006-00061A. There are no other changes to the hardware; i.e. triac and heatsink selection are per appendicies B and E respectively.

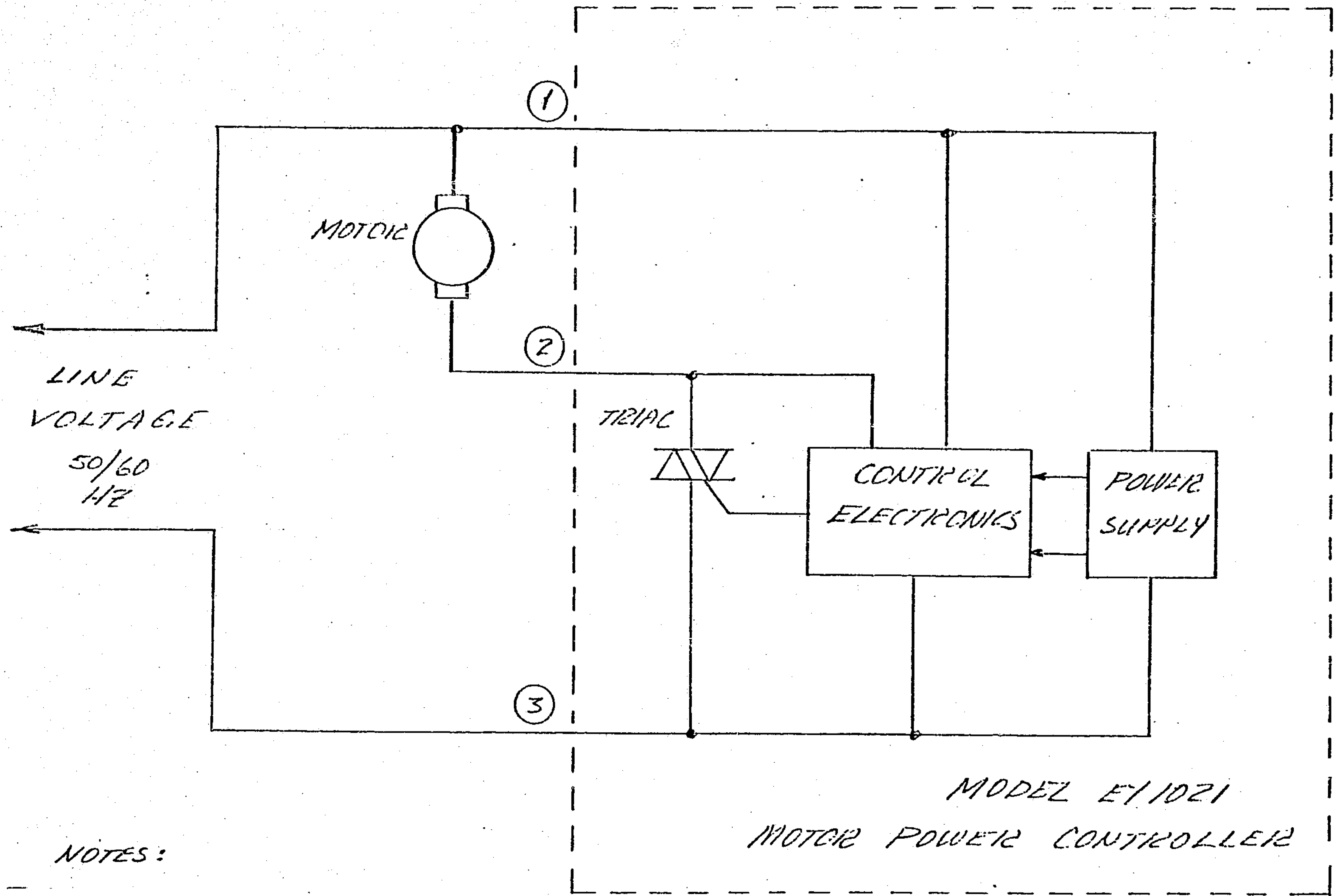
The units function identically except that the revised hardware has an added feature refered to as a "bump" circuit. The bump-circuit is made up of C 7, R 18, 19, 20, CR 9, and U2D. This circuit provides instant response to suddenly increasing or clutched-in loads.



POWER VS LOAD
CURVE

FIGURE 001

IVECO INC



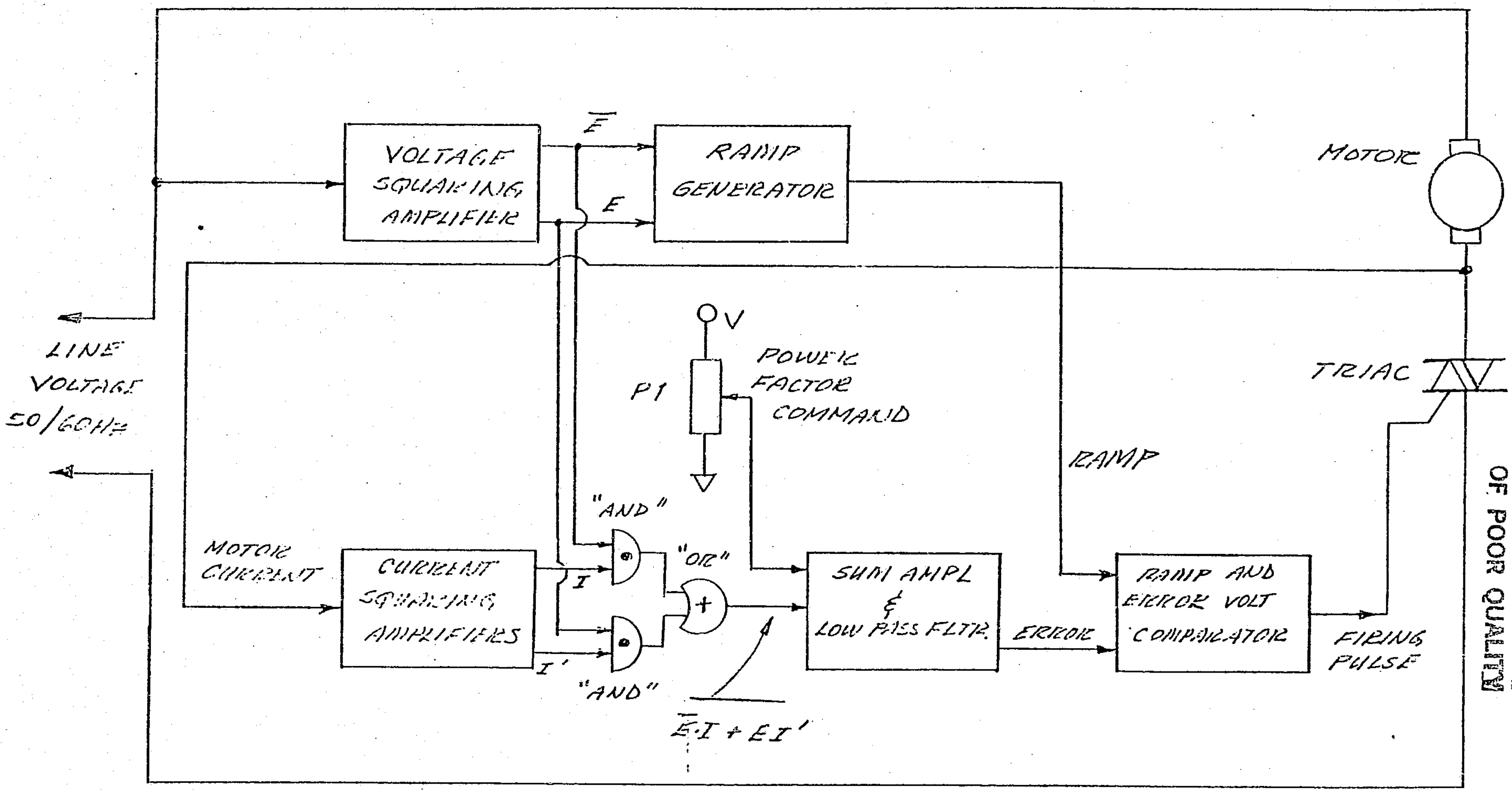
NOTES:

– Refer to HOOK-UP INSTRUCTIONS.

GENERAL BLOCK DIAGRAM

FIGURE 002

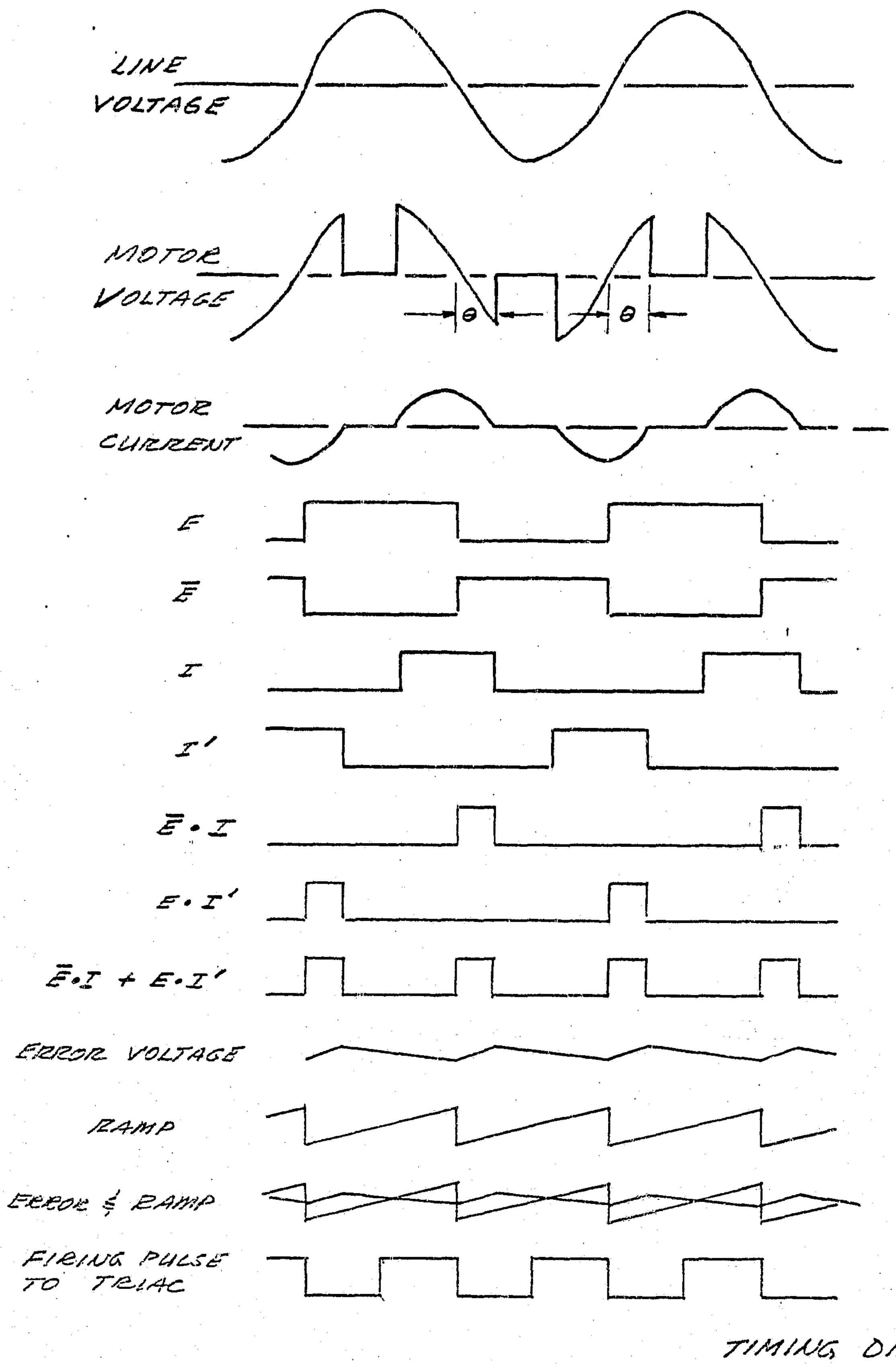
IVECO INC



ELECTRICAL BLOCK DIAGRAM
MODEL EY 1021
MOTOR POWER CONTROLLER

FIGURE 003

IVECO INC



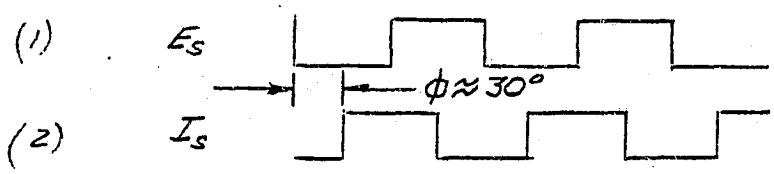
TIMING DIAGRAM
FIGURE 004

IVECO INC.

OPERATIONAL CHARACTERISTICS OF 1Ø UNIT

P/N EY1021

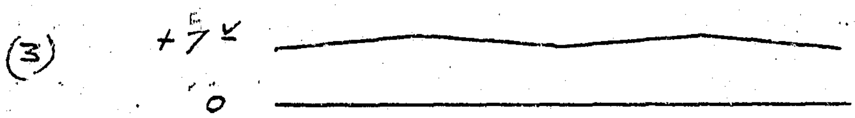
The voltage sense comparator output and the current sense comparator are square waves of opposite polarity with the voltage leading by 30 degrees to 45 degrees (This depends on the power factor, i.e. inductance of the motor. If the power factor is 1.0 it would be exactly 30 degrees). On a dual channel scope this will appear as:



The output of the integrator is a varing DC level from +7v to -7v. The level is determined by two factors,

1) The current leading angle (i.e. Motor Power Factor) .
2) The setting of the adjustment control. With the pot full CW the output will be full positive and the triac driven full ON. When the output goes below GnD the triac will be turned OFF.

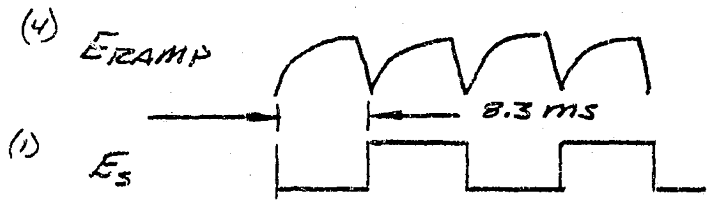
The signal will appear as:



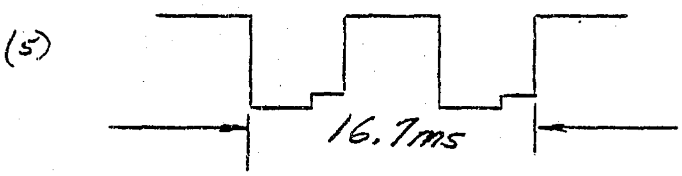
The output of the ramp generator is in sync with the voltage sense square wave. The negative edge creates one ramp, the positive edge creates another thus there is one for each cycle of the line voltage sine wave. The signal will appear as follows compared to the voltage sense:

OPERATIONAL CHARACTERISTICS OF 1Ø UNIT (con't)

P/N EY1021

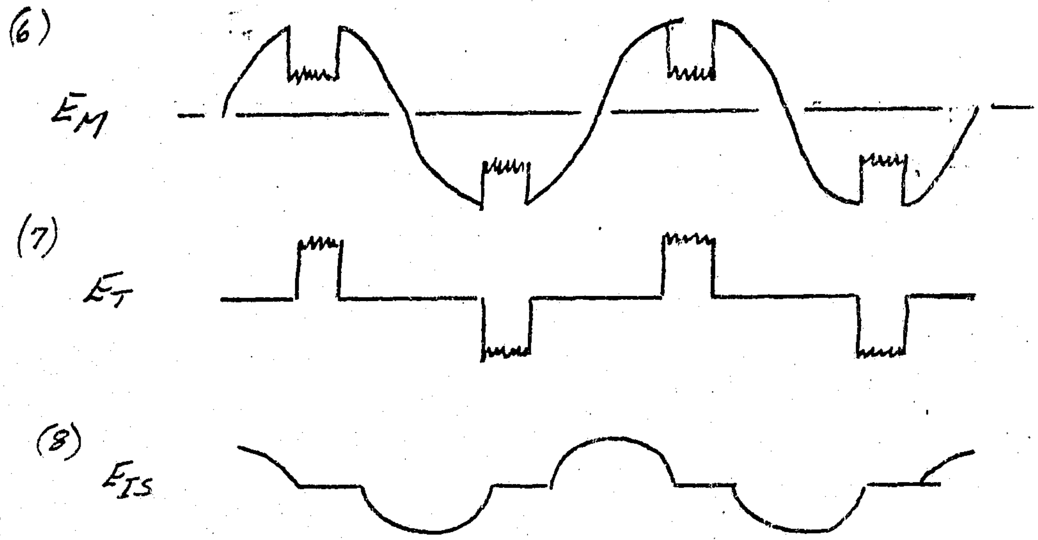


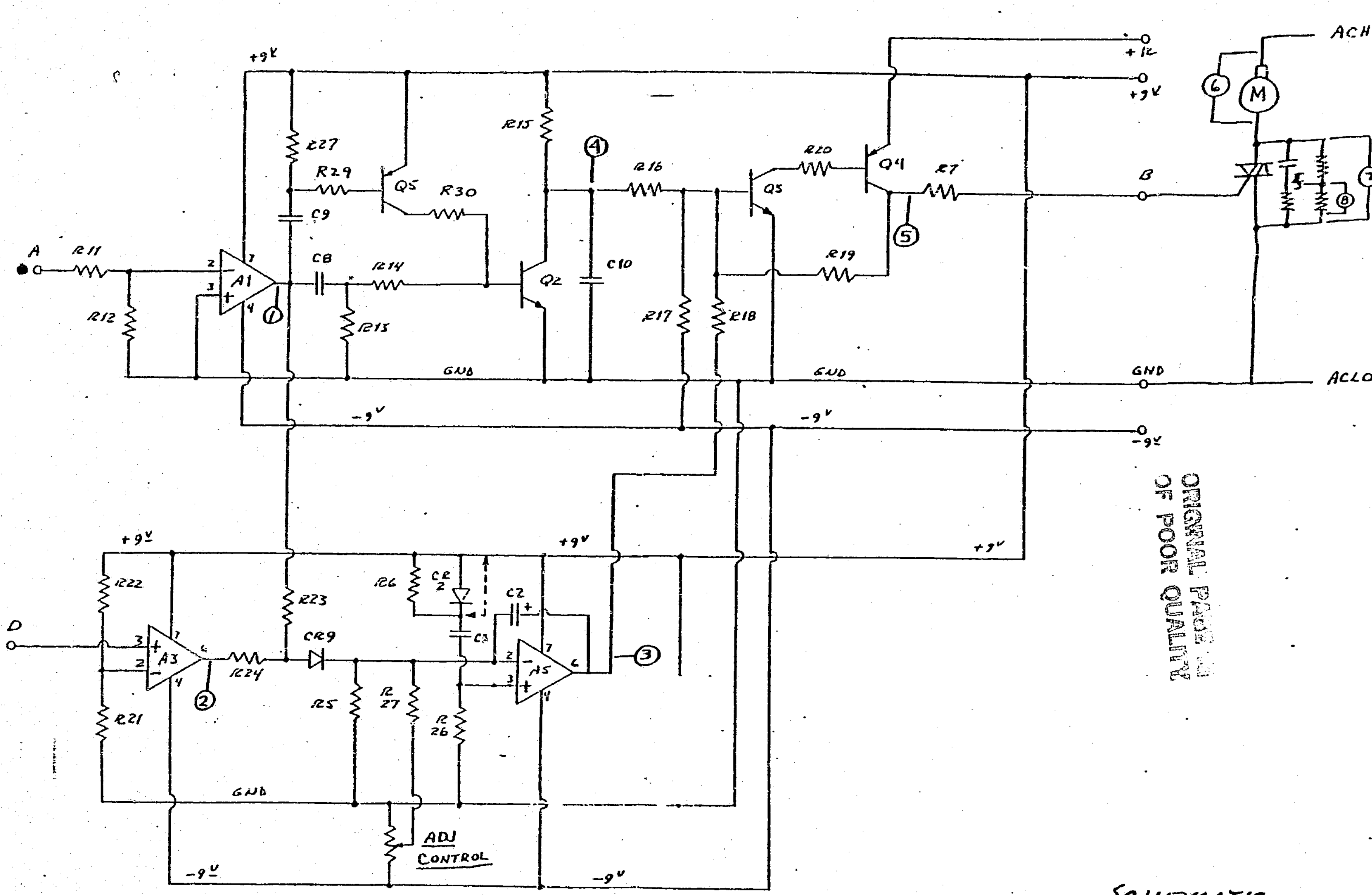
The output of the summing amp (Q3 & Q4) also provide the triacs gate drive current. A positive signal is required to turn ON the triac. With the adjustment control full CW (i.e. no control) the collector of Q4 will be at +7v. With the unit controlling the signal will appear as:



When the signal goes low the triac is turned OFF.

The voltage signals across the motor, triac and current sense is shown with respect to each other and the unit controlling with a retard angle of 30 degrees.



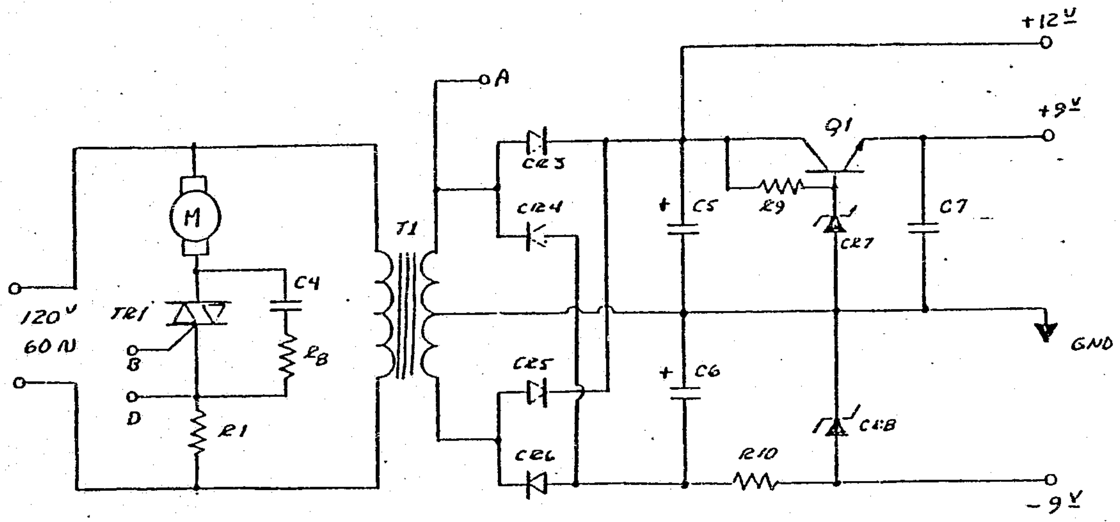


SCHEMATIC

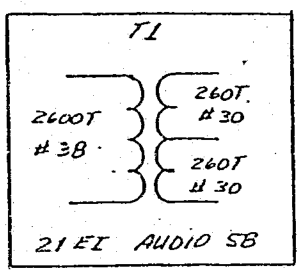
CONTROLLER ELECTRONICS

P/N E71021

Figure 005A



TR1 & R1 NEED HEATSINK

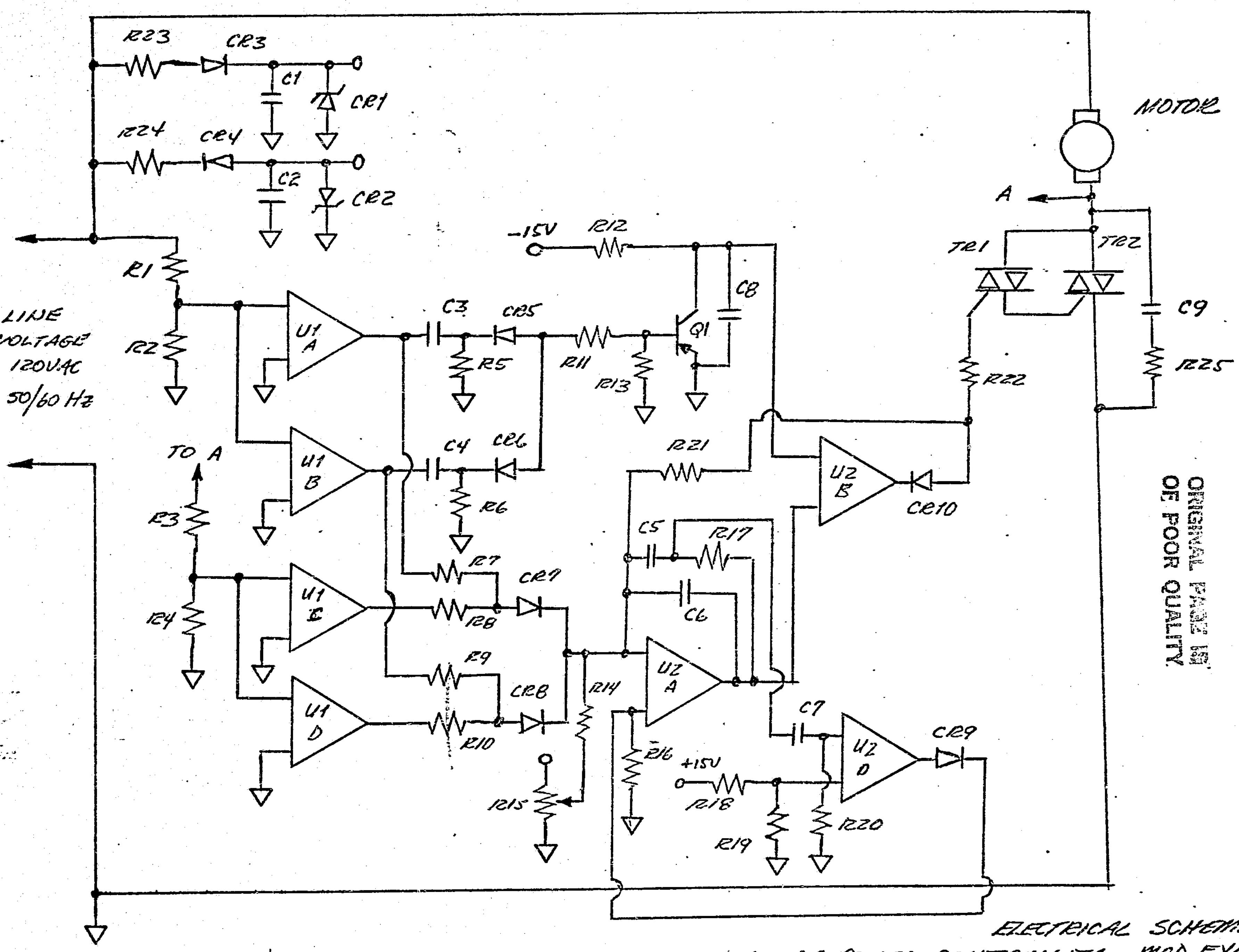


SCHEMATIC

POWER SUPPLY

P/N EY1021

Figure 005B



ELECTRICAL SCHEMATIC
MOTOR POWER CONTROLLER MOD EY1021
FIGURE 006

IVECO INC

APPENDIX A

MOTOR POWER CONTROLLER

SINGLE PHASE

MODEL EY1021

PARTS LIST

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Huntington Beach, CA 92647

DR	EY	DATE 11/30/80
APP	EY	11/30/4

SINGLE PHASE
MOTOR POWER CONTROLLER
MODEL EY 1021

PL 1021-006-00038A

REV 4

PARTS LIST	REF EQUIP NO	EY 1021 MPC	DATE PREPARED 11/30/80
	REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
01	2N2222A	Q1, 2, 3		SWITCHING TRANSISTOR	3
02	2N2907A	Q4, 5		SWITCHING TRANSISTOR	2
03	LM 741	A1, 2, 3		I.C. OP-AMP	3
04	1N4002	CR3, 4, 5, 6, 9		POWER DIODE	5
05	1N757A	CR7, 8		ZENER DIODE	2
06	1.0 MFD, 10V	C2		SOLID DIPPED TANALUM CAPACITOR	1
07	2.2 MFD, 10V	C3, C7		CAPACITOR MINEATURE ELECTROLYTIC	2
08	0.22 MFD, 400WVDC	C4		MYLAR CAPACITOR FILM WRAPPED TUBULAR	1
09	470 MFD, 30V	C5, C6		CAPACITOR MINEATURE ELECTROLYTIC	2
10	0.047 MFD, 10V	C8		MYLAR CAPACITOR POLYESTER FILM	1
11	0.01 MFD, 10V	C9		MYLAR CAPACITOR POLYESTER FILM	1
12	0.33 MFD, 10V	C10		MYLAR CAPACITOR POLYESTER FILM	1
13	~~4.7 MFD, 10V~~ 3.3K, 1/4 W, 5%	~~C11~~ R5		RESISTOR FILM OR CARBON COMP	1
14	150Ω, 2W, 1%	R7			1
15	47Ω or 51Ω, 1W, 5%	R8			1
16	1.0K, 1/4W, 5%	R9, R13			2
17	470Ω, 1/4W, 5%	R10		RESISTOR FILM OR CARBON COMP	1

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IVECO

PARTS LIST	REF EQUIP NO	EY 1021 MPC	DATE PREPARED 11/30/80
	REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
01	27K, 1/4W, 5%	R11, R12, R27		RESISTOR FILM OR CARBON COMP	3
02	9.1K,	R14, R29, R34			3
03	15K,	R15			1
04	68K,	R16			1
05	150K,	R17, R22, R26			3
06	1.0Meg,	R19, R33			2
07	3K,	R20, R32			2
08	200Ω,	R21			1
09	20K,	R23			1
10	36K,	R24			1
11	5.6K,	R28, R30			2
12	39K,	R18			1
13					
14	20KΩ POTENTIOMETER	R25		10T 830P203 or EQUIV.	1
15					
16	A1-3 EY1021			PRINTED CIRCUIT BOARD	1
17					

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PARTS LIST

REF EQUIP NO	EY1021 - MPC	DATE PREPARED 11/30/80
REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
01	1STS003 OR EQUIV			TERMINAL STRIP	1
02	1STS004 OR EQUIV			TERMINAL STRIP	1
03	SC 464 NK			ENCLOSURE SCREW COVER PULL BOX	1
04	SCF 68			COVER, FLUSH SCREW COVER PULL BOX	1
05					
06					
07					
08					
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IVECO

PARTS LIST	REF EQUIP NO	EY1021 MPC	DATE PREPARED 11/30/80
	REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
01	SEE NOTE			TRIAC	1
02	1/4" HOLE DIODE MOUNT			MYLAR INSULATOR	2
03	1/4" HOLE			SOLDER LUG	1
04	1/4" HOLE FIBER INSERT			INSULATOR INSERT	1
05					
06					
07					
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	APPROVED	EY	OF 5		

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NOTES

1	TR1 is TECOR L400E3 or NEC ACOV8BGM(120VAC), ACOV8DGM(240VAC).
2	Enclosure: Use DD-0014 for NEMA 1 or DD-0015 for NEMA 3R.
3	Heatsink: Refer to DD-0013 for heatsink selection.
4	Refer to DD-0016 for wire size selection

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DR [signature] DATE 2/20/81	MOTOR POWER CONTROLLER MODEL EY1021 REVISION
APV [signature] 2/22/81	
	PL 1021-006-0006A REV A

PARTS LIST	REF EQUIP NO	EY 1021	DATE PREPARED 2/20/81
	REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
	27Ω, 1/2W, 5%	R25		RESISTOR	1
	2.4KΩ, 1/4W, 5%	R22			1
	3.3K, 1/4W, 5%	R19			1
	3.9K, 1/4W, 5%	R5, R6, R11			3
	5.1K, 3W, 5%	R24			1
	10K, 3W, 5%	R23			1
	12K, 1/4W, 5%	R2, R4, R13			3
	18K, 1/4W, 5%	R16			1
	51K, 1/4W, 5%	R17			1
	62K, 1/4W, 5%	R14			1
	120K, 1/4W, 5%	R7 THRU R10 & R18			5
	150K, 1/4W, 5%	R20			1
	180K, 1/4W, 5%	R12			1
	200K, 1/4W, 5%	R1 & R3			2
	510K, 1/4W, 5%	R21		RESISTOR	1
	27K, 1/4W, 5%	R26			1
	25K, 10TURN			POTENTIOMETER	1

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PARTS LIST

REF EQUIP NO	EY1021	DATE PREPARED 2/20/81
REF ASSY NO		DATE REVISED

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
	0.01 MFD, 25V	C3, C4		POLYESTER CAPACITOR	2
	0.1 MFD, 25V	C8		POLYESTER CAPACITOR	1
	0.22 MFD, 25V	C7		POLYESTER CAPACITOR	1
	0.25 MFD, 200V	C9		TUBULAR MYLAR CAPACITOR	1
	0.27 MFD, 25V	C5, C6		POLYESTER CAPACITOR	2
	100 MFD, 30V	C1, C2		CAPACTOR	2
	1N965	CR1, CR2		DIODE	2
	1N483	CR5 THRU CR11		DIODE	7
	1N645	CR3, CR4		DIODE, ZENER	2
	2N2907A	Q1		TRANSISTOR	1
	LM324	U1, U2		QUAD OP-AMP INTEGRATED CIRCUIT	2
	SEE IVECO DD-300	TR2		TRIAC	1
	SEE NOTE 1	TR1		TRIAC	1

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PARTS LIST

REF EQUIP NO	EY1021	DATE PREPARED	2/20/81
REF ASSY NO		DATE REVISED	

ITEM	PART NUMBER	REF DESIG	SOURCE CODE	DESCRIPTION	QTY
	SEE NOTE 2			ENCLOSURE	1
	SEE NOTE 3			HEATSINK	1
	TS 0004			TERMINAL STRIP	1
	6-32 x 1/2			Nut, Bolt, Lockwasher	4
				Rivet	5
				Standoff	4
	SEE NOTE 4			WIRE	AR
				Triac Mounting Hdwr	1 Set

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APPENDIX B

TRIAC SELECTION
SINGLE PHASE MPC

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17402 Coronado Lane
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DR EY DATE 2/20/81	TRIAC SELECTION SINGLE PHASE MPC MODEL EY1021
APV EY	
Pg 1 of 3	DD-0012 A

TRIAC SELECTION - 1φ MPC

HP	FLA	V (MOT)	PD	TRIAC	I_T	V_{DRM}	HS
1	8.3	120	10	2N5573	15	200	A
				T4120B	15	200	A
				SC250B(or B4)	15	200	A1
1	8.3	240	5	2N5574	15	400	A
				T4120D	15	400	A
				SC250D(or D4)	15	400	A1
3	24.9	120	30	T6420B	40	200	B
				SC265B(or B4)	40	200	B
3	12.5	240	15	T6421D	30	400	A
				SC260D(or D4)	25	400	A
5	41.4	120	50	T8411B	60	200	C
5	20.7	240	25	T6421D	30	400	B

NOTES:

1. Refer to IVECO DD-0013 for Heat Sink A
   Refer to IVECO DD-0013 for Heat Sink B
   Refer to IVECO DD-0013 for Heat Sink C
2. Calculations based on:

$$I_{FLA} = \frac{(746)\,HP}{V(MOT)\,(eff \,\&\, pf)}$$

where: $(eff \,\&\, pf) \triangleq 0.75$

3. All triacs are isolated types.

Edward [signature]

SINGLE PHASE MPC
TRIAC SELECTION

 DD-0012 REV A

DEFINITIONS

HP	Horsepower
FLA	Full Load Amps (associated with motors)
V(MOT)	Motor Voltage (line)
PD	Power Dissipation in triac element (or SCR) in Watts
I_T	Triac steady-state current maximum.
V_{DRM}	Triac OFF-state maximum voltage.
HS	Heat Sink.

SINGLE PHASE MPC
TRIAC SELECTION

APPENDIX C

U.S. PATENT 5,052,648

POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

United States Patent [19]

Nola

[11] **4,052,648**

[45] **Oct. 4, 1977**

[54] **POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS**

[75] Inventor: **Frank J. Nola**, Huntsville, Ala.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[21] Appl. No.: **706,425**

[22] Filed: **July 19, 1976**

[51] **Int. Cl.**[2] **H02K 17/04**

[52] **U.S. Cl.** **318/200**; 318/227; 318/230

[58] **Field of Search** .... 318/200, 227, 230, 231, 318/221 R, 216

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,441,823 4/1969 Schlabach .... 318/221 R

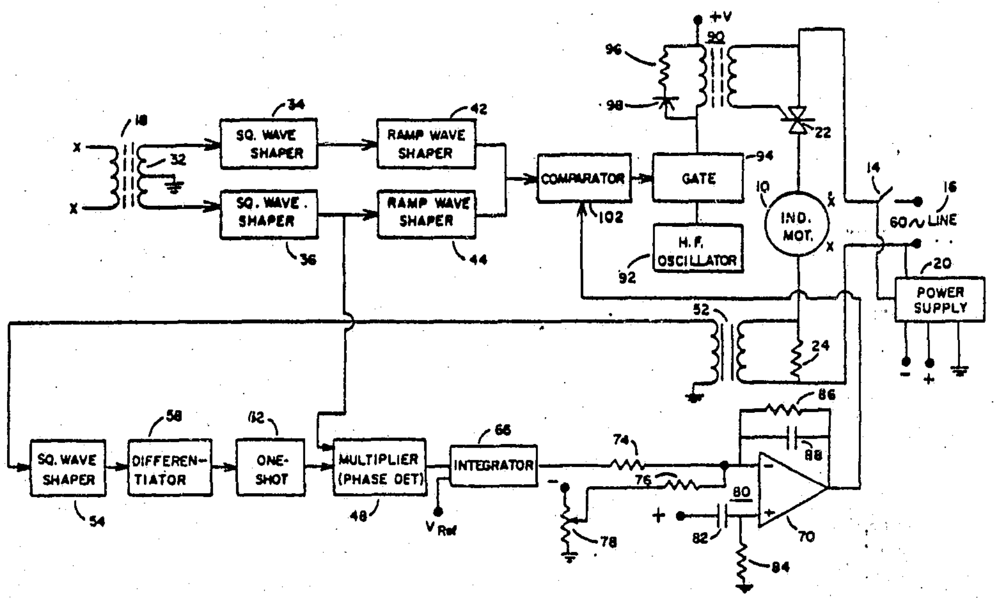
Primary Examiner—Herman J. Hohauser

Attorney, Agent, or Firm—L. D. Wofford, Jr.; George J. Porter; J. R. Manning

[57] **ABSTRACT**

A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage to thereby provide less power to the motor, as it is less loaded.

5 Claims, 3 Drawing Figures



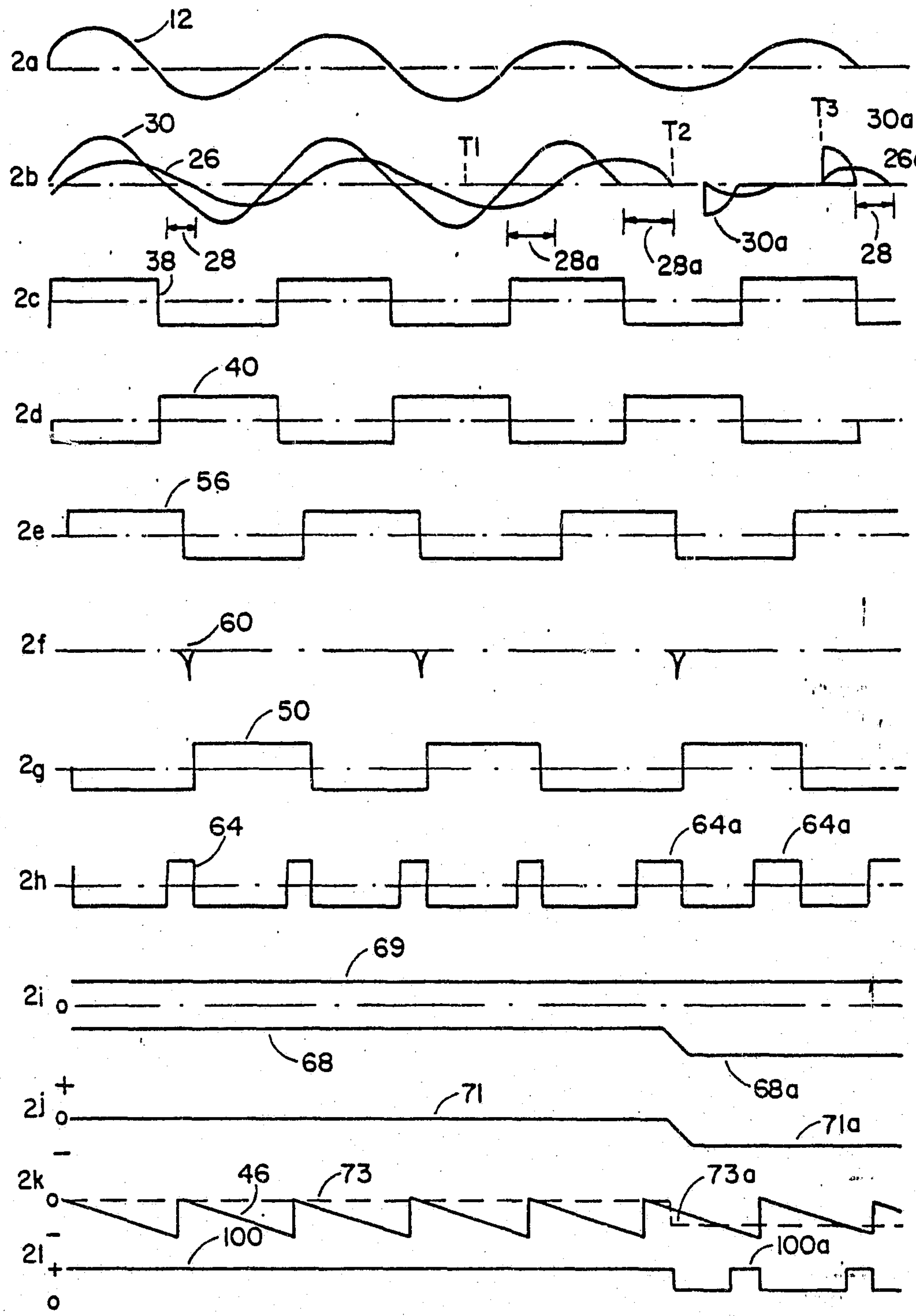


FIG. 2

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POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art

The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Heretofore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal 115-volt service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention

It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will effect a reduction in power normally provided the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical schematic diagram of an embodiment of the invention.

FIGS. *2a–2l* are waveforms illustrating aspects of operation of the invention.

FIG. 3 is a plot illustrating power drawn by a motor for different states of loading and with and without the control system of this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An AC induction motor 10 is powered by an alternating current voltage 12 (FIG. *2a*) through switch 14 and connectible at terminals 16. The switched AC power is also applied to transformer 18 and circuit bias power supply 20. Triac 22 is connected in series with motor 10 and is triggered for controlled portions of each half cycle of power input. A small value resistor 24 of 0.010 to 0.020 ohms is connected in series with motor 10 and serves to develop a signal 26 (FIG. *2b*) which is proportional to the current flow through the motor. FIG. *2b* illustrates an instantaneous state of operation after initial start-up and with an initial optimum input voltage-load relationship, whereby triac 22 is fully on and where, thereafter, loading is substantially decreased. The initial current-voltage phase lag 28 for such optimum state of operation may vary from motor to motor and would be determined for each motor with which this invention is to be employed. In the present example, initially, optimum phase lag 28 is approximately 30°, and potentiometer 78 is adjusted to provide the zero error output signal for the control of the turn on time of triac 22 to maintain the phase angle of this or another selected value. The occurrence of increased current lag *28a* at time T_1 depicts a sudden decrease in loading of motor 10. The detection of this is used, as will be further explained, to reduce the average amplitude of input voltage and thereby to effect a commanded, optimum, phase lag.

To further examine the circuitry, transformer 18, having center tap secondary 32, provides oppositely phased inputs to square wave shapers 34 and 36, and the resulting oppositely phased outputs, square wave 38 (from shaper 36) shown in FIG. *2c* and square wave 40 (from shaper 34) shown in FIG. *2d*, which are fed to saw tooth or ramp wave shapers 42 and 44, respectively. The outputs of the wave shapers are combined to provide a ramp wave each half cycle of the alternating current input as shown in waveform 46 of FIG. *2k*. Waveform 38 is also used as a reference signal for the phase of input voltage and is fed to one input of multiplier 48, functioning as a phase detector, to which is also fed a current reference signal 50 shown in FIG. *2g*. The current reference signal is generated as follows. Current signal 26 (FIG. *2b*) from resistor 24 is fed to isolation transformer 52 and from it to square wave pulse shaper 54, which provides square wave 56 (FIG. *2e*). This square wave is differentiated in differentiator 58 to provide spike pulses 60 shown in FIG. *2f*, and the negative pulses (derived from the trailing edge of square wave 56) are used to trigger one-shot 62, which provides as an output the square waveform 50 shown in FIG. *2g*. This square waveform commences at a time corresponding to the trailing or zero crossing point of current signal 26 (FIG. *2b*) and has a duration (determined by the time constant of one-shot 26) corresponding to the length of a half cycle of AC input to the motor. Thus, there is generated a square wave current signal which is of the

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Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:

current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;

voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;

phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing an output which varies in accordance with the difference in phase between said current and said voltage; and

a control means adapted to be electrically connected in series with each said winding of said motor, and responsive to the output of said phase detection means for varying the duration of "on" time of each cycle of input power to said winding inversely proportional to the difference in phase between said current and said voltage;

whereby an increase in difference between the magnitude of said voltage and the magnitude of load applied to said motor is compensated for by a reduction in power to said motor, generally improving its efficiency.

2. A control system as set forth in claim 1 wherein said current sampling means includes a resistor adapter to be placed in series with a said winding and means for

providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein:

said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and

said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

4. A control system as set forth in claim 3 wherein said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

5. A control system as set forth in claim 4 wherein said control means includes:

means responsive to the voltage applied to said winding of said induction motor for providing a saw tooth wave at double the frequency of said voltage;

pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and

switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.

* * * * *

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APPENDIX D

SET-UP INSTRUCTIONS

MODEL EY1021 MPC

PROCEDURE FOR
ELECTRCIAL SET-UP OF MOTOR POWER CONTROLLER
EY1021 SERIES
115 VAC, 50/60 Hz
230 VAC, 50/60 Hz

The following is a procedure for adjustment and "peaking" the EY1021 Motor Power Controller. To achieve adjustment for maximum power savings, the motor should be at no-load or at some constant load less than full load. DO NOT try to make adjustment when the motor is under varying load. A light load on the motor is recommended.

Apparatus/Tools Required

1. A small Screwdriver
2. A clamp-on Ammeter

Step 1. Locate "Phase-Angle Adjust" potentiometer; See figure 1.

Step 2. Turn "phase-angle adjust" pot clockwise for 10 full turns.

Step 3. With power-OFF, attach the motor power controller as shown in the attached drawing No. 1021-012-000002, entitled "Electrical Interface".

Step 4. Start motor/controller system and allow five minutes warm-up before continuing.

Step 5. Using the clamp-on ammeter measure the current in motor lead No. 2; note current. See figure 2.

Step 6. While observing the ammeter, turn phase-angle adjust pot clockwise; there should be no change in metered current. If current does increase, continue turning the adjustment potentiometer clockwise until no current change can be seen.

Step 7. Slowly turn "phase-angle adjust" potentiometer counterclockwise until motor current, as shown on the meter, begins to decrease.

Step 8. Continue turning the potentiometer counterclockwise very slowly while watching the meter. When the motor current levels off and shows a slight increase---STOP immediately and reverse the adjustment direction so as to bring the current back slightly. THE ADJUSTMENT IS COMPLETE.

NOTE: If, in following this procedure, no dip in current is noticed (apparent using some motors) set the controller for the lowest possible position at which the motor responds to load change increases without stall.

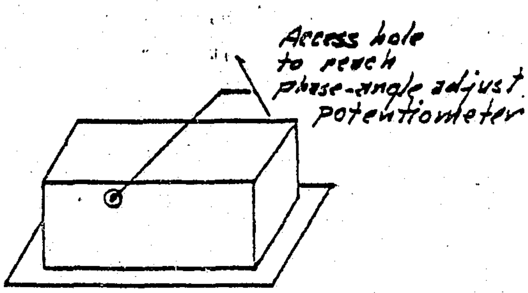


Figure 1

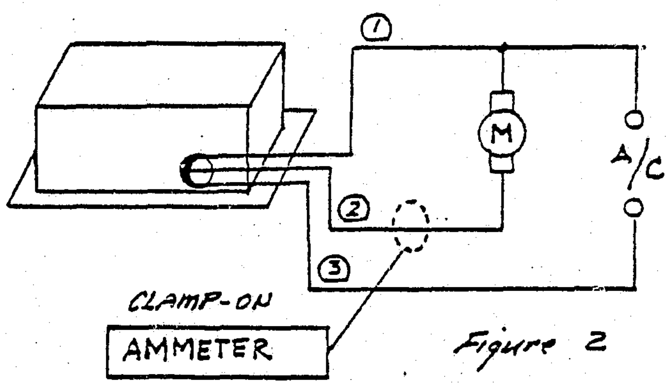
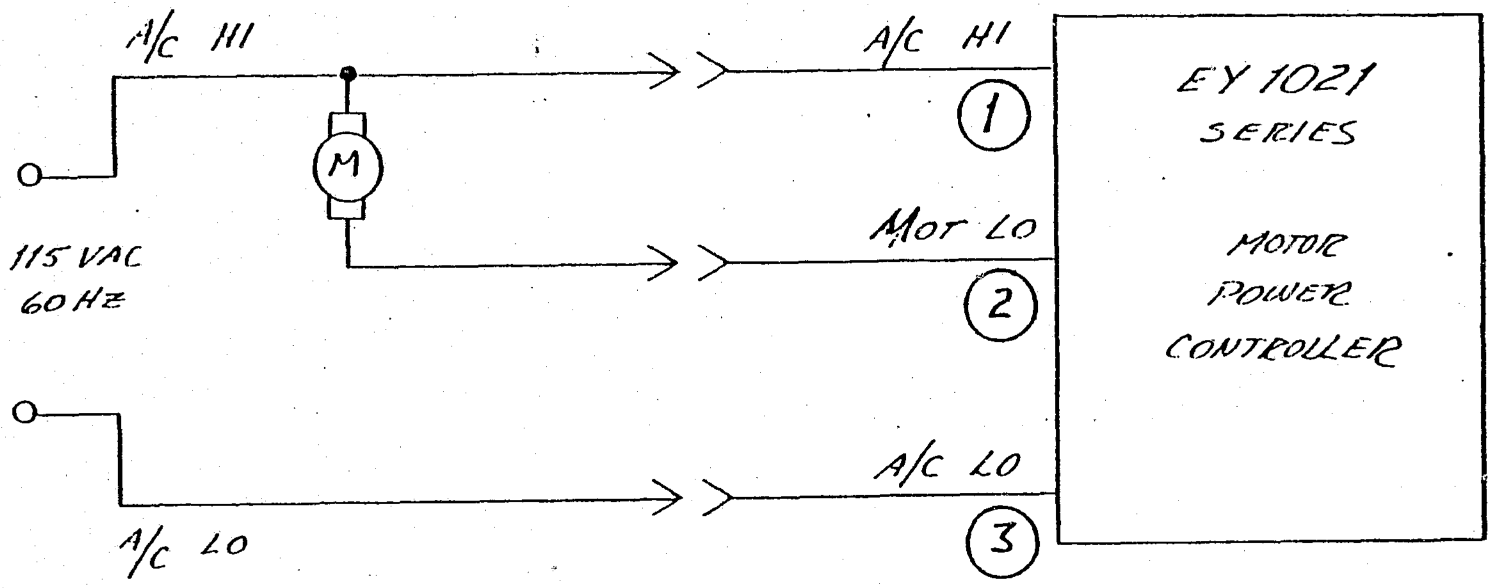


Figure 2

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647
(714) 842 - 2925



MODEL EY1021
ELECTRICAL INTERFACE

4/4/80 EU	IVECO IMPROVEMENT VIA ELECTRONICS 17402 Coronado Lane Huntington Beach, CA 92647
	1021-012-00002 A

APPENDIX E

HEATSINK SELECTION
SINGLE PHASE MPC

MODEL EY1021

HP	VOLTAGE (AC)	PD in Watts	Heat Sink IVECO Desig	Remarks
1	120	10	A (or A1)	IVECO Dwg # 1021-010-00029A for A
1	240	5	A (or A1)	IVECO Dwg # 1021-010-00028A for A1
3	120	30	B (or B1)	IVECO Dwg # 1021-010-00041A for B and 00040A for B1
3	240	15	A (or A1)	(see above)
5	120	50	C	IVECO Dwg #
5	240	25	B	IVECO Dwg # 1021-010-00041A

Notes: Replacement for B; refer to IVECO Dwg # 1021-010-00060A.

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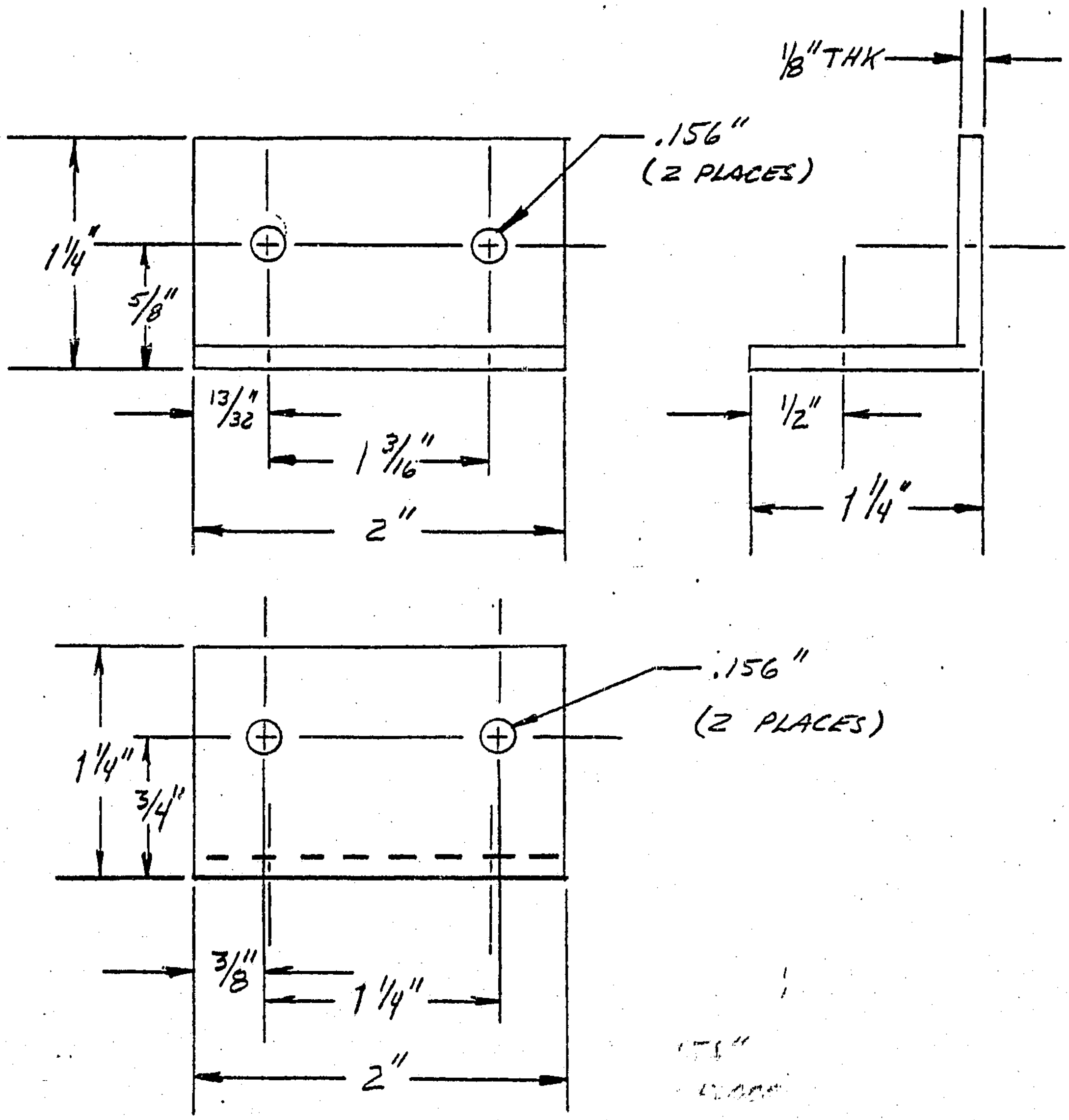
REV	A	A	A	A	A	A	A														
Pg																					
REV																					

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

DR EY DATE 2/20/81
APV EY 2/20/81

HEATSINK SELECTION
SINGLE PHASE MPC
MODEL EY1021

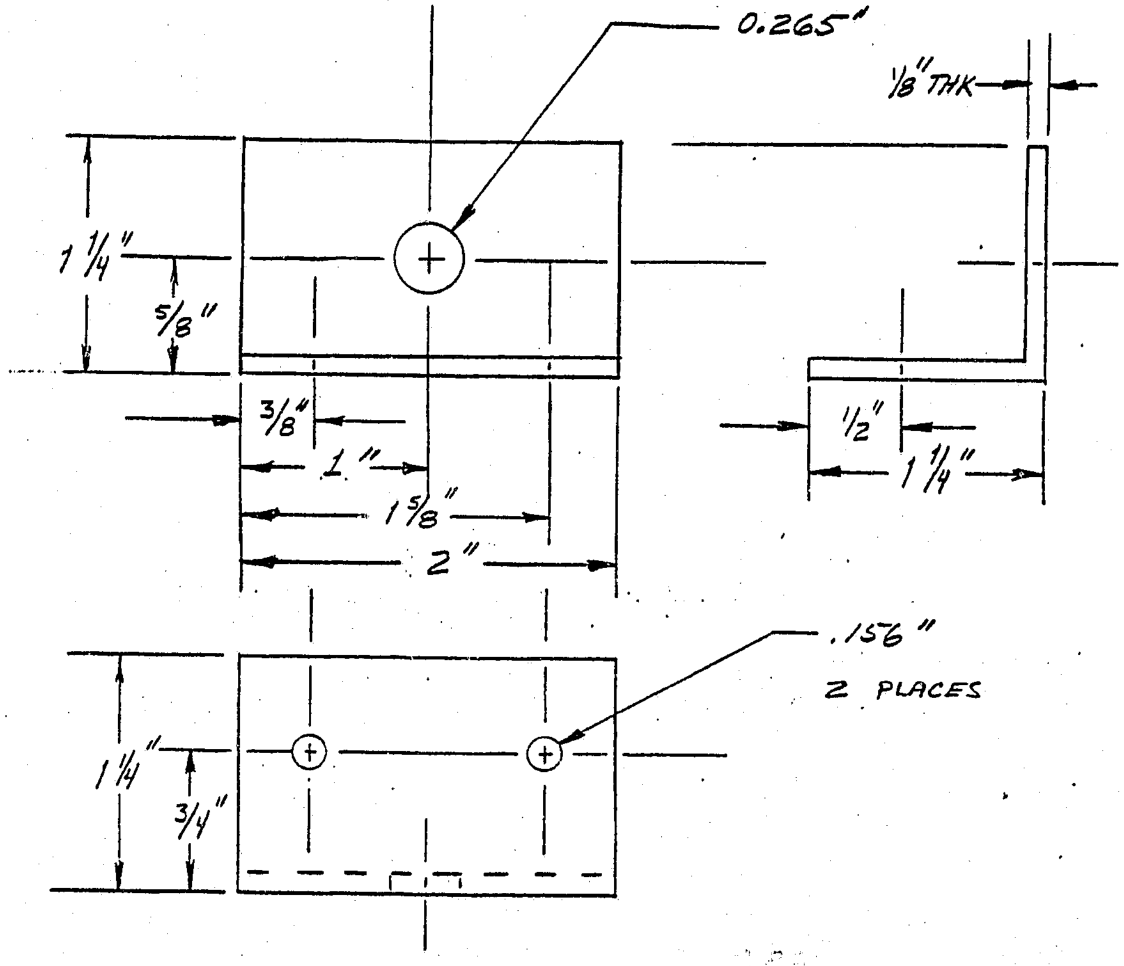
P1 of 2 | DD- 0013 | A



NOTES:

1. MAKE FROM 1 1/4" x 1 1/4" x 1/8" STANDARD 6063-T5 ALUMINUM EXTRUSION.

	IVECO 5762 RESEARCH DR HUNTINGTON BEACH CA 92649
10/80 EH	TITLE BRACKET SINGLE-PHASE HEATSINK TO-3 FLANGE TRIAC
	DWG. # 1021-010-00028 A — REV A



NOTES:

1. MAKE FROM 1¼" x 1¼" x ⅛" STANDARD 6063-T5 ALUMINUM EXTRUSION.

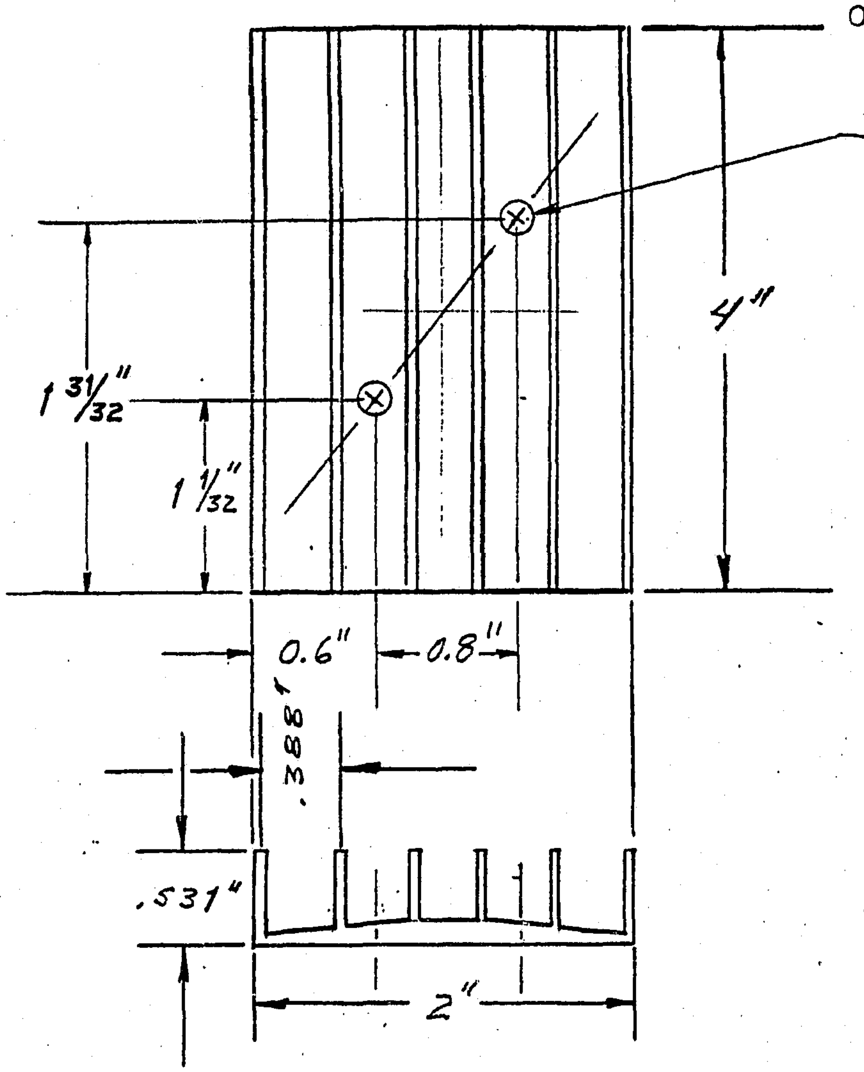
IVECO INC
5762 RESEARCH DR.
HUNTINGTON BEACH CA 92649

TITLE BRACKET
SINGLE-PHASE HEATSINK
STUD-MOUNTED TRIAC

10/80 EM

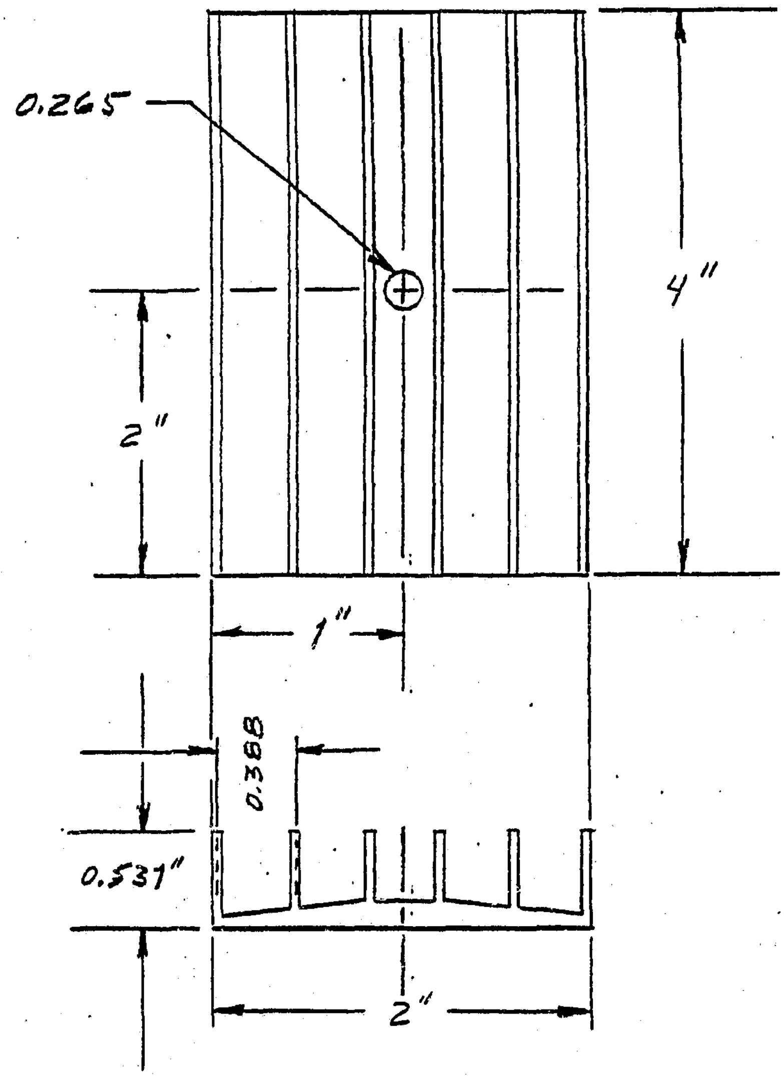
DWG # 1021-010-00029A

REV A



1. Use AAVID P/N 60885, or equivalent, in 4 inch lengths
2. 9.5 sq"/1", 0.5 lb/2", 5.2 c/w/3"

	IVECO INC 5762 Research Dr Huntington Beach, CA 92649
EY 11/3/80	EXTERNAL HEATSINK SINGLE-PHASE MPC TO-3 FLANGE MOUNT
Scale 1/1	1021-010-00040A | A



Notes:

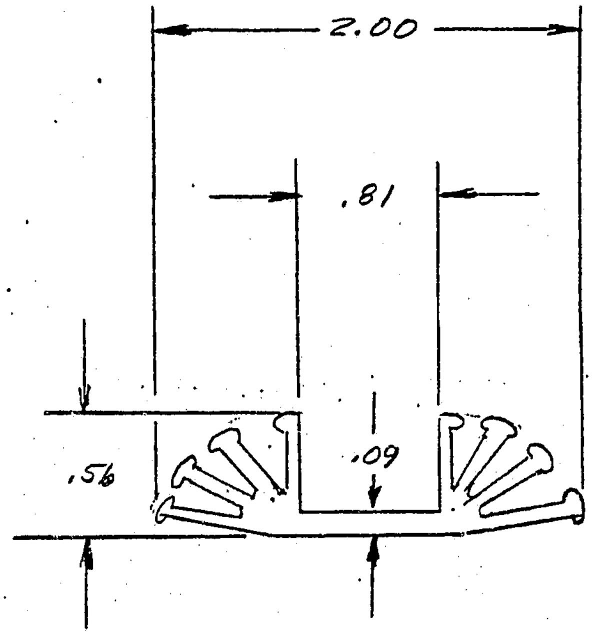
1. Use AAVID P/N 60685 or equivalent, in 4 in lengths
2. 9.5 sq"/1", 0.5 lb/1", 5.2C/W/3".

	IVECO INC 5762 Research Dr. Huntington Beach CA 92647
EH 11/4/80	EXTERNAL HEATSINK SINGLE-PHASE MPC STUD MOUNT
Scale 1/1	1021-010-00041A | A

Therm Resistance

1.5"	3.0"	5.5"	
9.2°	6.1°	4.2°	
c/w	c/w	c/w	

3Hp @ 24.9 FLA : 30W = 183°
3Hp @ 12.5 FLA : 15W = 92°
5Hp @ 20.7 FLA : 25W = 152.5°



NOTES
1. WEI CORP P/N 3160 or equiv
2. CUT IN 3.00 inch lengths
3. 1 HS per unit
4. 1/4 inch hole in center for triac mount

WEI Corp
1405 S Village Way
Santa Ana CA 92705
(714) 834-9333

Dr. EY 2/20/81
App EY 2/20/81

IVECO INC
5762 Research Dr
Huntington Beach CA
92649

3/5 HP HEAT SINK 1 Φ MPC
MODEL EY1021

Page 1 of 1

DWG # 1021-010-00060A | A

APPENDIX D

NASA TECH BRIEF MFS23280

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APPENDIX D

POWER FACTOR CONTROL SYSTEM

FOR AC INDUCTION MOTORS

US PATENT NO. 4,052,648

IVECO LICENSE NO. 477

NASA Tech Brief
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama

MFS-23280
Summer 1977

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Save Power in AC Induction Motors

Electronic control loop conserves energy by reducing the voltage applied to lightly loaded motor.

Relatively simple and inexpensive circuitry will improve the power factor and reduce power dissipation in induction motors operating below full load. Power factors as low as 0.1 or 0.2 can exist when such motors are partially loaded or unloaded. When this is the case, relatively large currents flow, and little work is being performed. Hence, I^2R losses will occur at all points in the distribution system, including the motor windings, even though no mechanical power is delivered.

An electronic control system has proved, under tests, capable of raising power factors from 0.2 to 0.8 and resulting in energy savings as shown in Figure 1. The power losses are reduced by sensing the phase lag between the voltage and current. This information is fed to the electronic controller shown in Figure 2. This circuit forces the motor to run at a constant predetermined optimum power factor, regardless of load or line voltage variations (within the limits of the motor).

Voltage is varied by using a solid-state switch (such as a Triac or equivalent), which blocks current in either direction until a gate voltage is applied, at which point it will conduct in either direction. When the gate voltage is removed, the Triac remains on until the current goes through zero. Current does not flow again until the gate voltage is applied again. To vary the RMS voltage applied to a motor, the gate is triggered at a given point during the cycle, and the device switches off as the current goes through zero.

The circuitry in the top half of Figure 2 is a typical phase-control and firing-angle circuit. Voltage V_1 is a ramp waveform with its vertical portion synchronized with the zero crossings of the sinusoidal load voltage; V_2 is a dc error signal; and V_3 is a train of pulses that become wider as the error signal increases. When the pulse is positive, a voltage will be applied to the gate of the Triac.

The error signal is derived in the circuitry in the lower half of Figure 2.

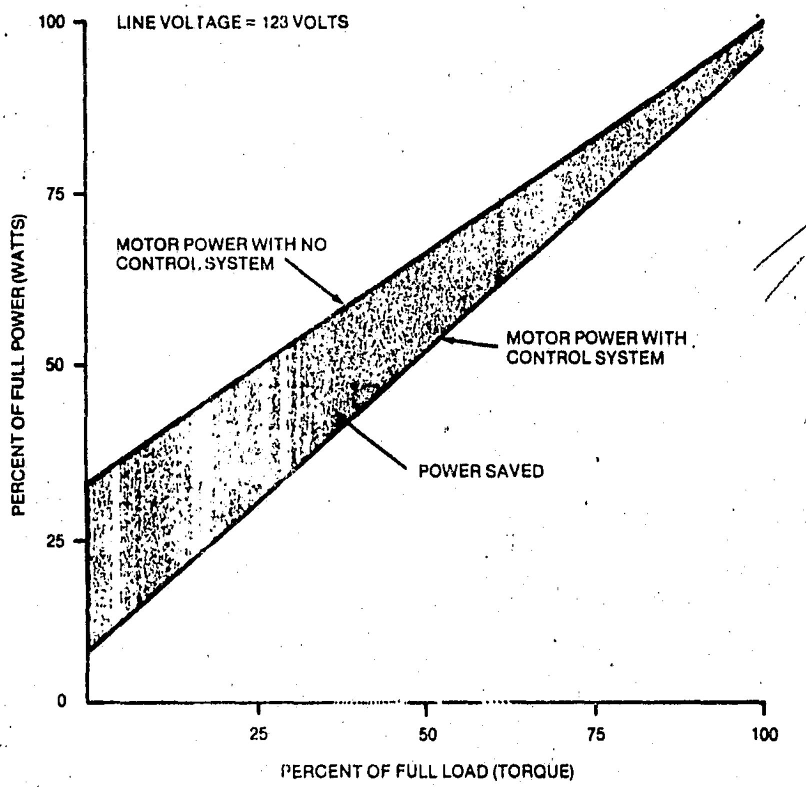

Figure 1. Power Saved is shown as averaged from tests made on a 1/3-hp split-phase motor and 1/4- and 3/4-hp capacitor-start motors. The top curve is the total power taken as a function of load with no control system. The bottom curve represents the total power with the voltage controlled by the circuit in Figure 2. Curves are plotted as percent of full power versus percent of full load. The circuit reduced the no-load power by a factor of 5 or 6 and increased the power factor from 0.2 to 0.8. In all three motors, the slowdown due to reducing the applied voltage was less than 2 percent.

(continued next page)

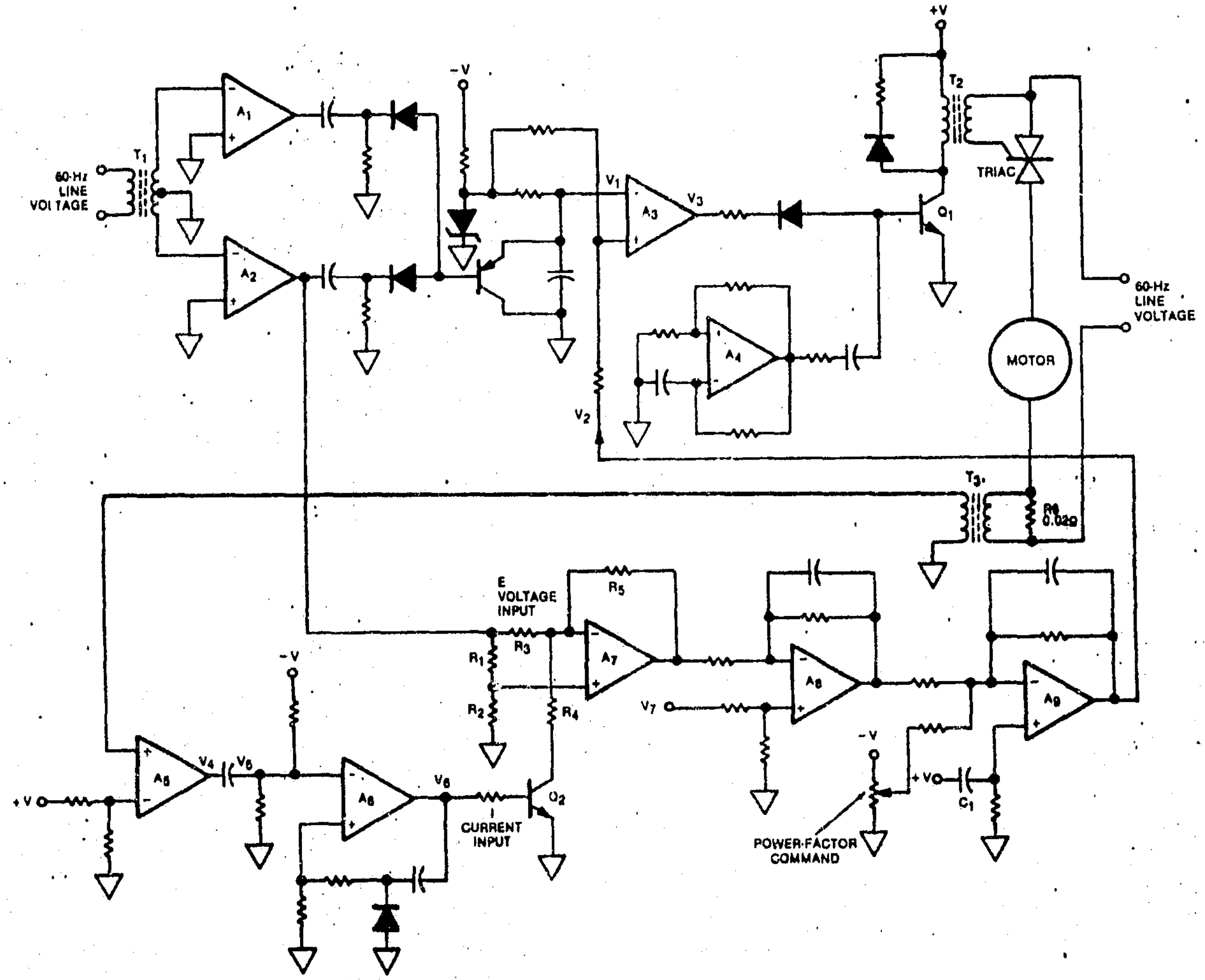

Figure 2. The Electronic Control Circuit consists of a typical phase-control circuit (top half) and a new circuit that senses the voltage/current phase lag in an ac inductor motor. This phase lag is used to produce an error signal (V_2) for the phase-control circuit, where a control pulse is developed to switch a Triac that regulates the motor voltage in response to loads.

The phase lag between the voltage and current in the motor is sensed and is used to produce a dc voltage proportional to phase lag. This signal is fed back and summed with a power factor command signal. The difference between these two voltages is an error signal (V_2) that drives amplifier A_3 and controls the voltage to the motor.

This work was done by Frank J. Nola of **Marshall Space Flight Center.** *For further information,* Circle 3 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page A8]. Refer to MFS-23280.

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1. TITLE

Power Factor Control System for Improved Efficiency in an AC Induction Motor

2. INNOVATOR(S) *(Name and Social Security No.)*

Frank J. Nola

3. EMPLOYER *(Organization and division)*

NASA-MSFC
EC24

4. ADDRESS *(Place of performance)*

Marshall Space Flight Center, AL

5. DOCUMENTATION *(Full and complete disclosure, must be enclosed, the contents of which are discussed in NHB 2170.3, Documentation Guidelines for New Technology Reporting. Place an "X" to the left of those items of documentation which are available but NOT enclosed with this transmittal)*

	ENGINEERING SPECIFICATIONS		OPERATING MANUALS		COMPUTER TAPES/CARDS
	ASSEMBLY/MFG DRAWINGS		TEST DATA		
	PARTS OR INGREDIENTS LIST		ASSEMBLY/MFG PROCEDURES		

6. PREVIOUS PUBLICATION OR PUBLIC DISCLOSURE

PUBLICATION ▶

TYPE: ☐ JOURNAL ☐ REPORT ☐ CONFERENCE OR SEMINAR

BY: ☐ NASA ☐ OTHER GOVT. ☐ CONTRACTOR ☐

VOLUME NO.	PAGE	DATE	STATUTORY BAR ESTABLISHED *(Date)*

TITLE

PATENT ▶

STATUS: ☐ APPLICATION FILED ☐ ISSUED

NO.

DATE

7. STATE OF DEVELOPMENT

☐ CONCEPT ONLY ☐ DESIGN ☐ PROTOTYPE ☐ MODIFICATION ☐ PRODUCTION MODEL ☐ USED IN CURRENT WORK

8. ORIGIN *(CC 12)*: N (12)

9. NASA PRIME CONTRACT NO. *(CC 13-23)*: 13 14 15 16 17 – 18 19 20 21 22 23

10. SUBCONTRACT TIER *(CC 24)*: 24

11. CONTRACTOR REPORTABLE ITEM NO. *(CC 25-33)*: 25 26 27 28 29 30 31 32 33

For Internal Use Only

12. CONTRACTOR/GRANTEE NEW TECHNOLOGY *Not* SUBMITTED PURSUANT TO NT/PRI CLAUSE PROVISION *(CC 34)* ☐

13. SUBCONTRACTOR CIC *(CC 35-41)*: 35 36 37 38 39 40 41

14. NT RECEIPT DATE *(CC 42-47)*

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15. PROJ. NO. *(CC48-51)*: 48 49 50 51

16. EVALUATION ORGANIZATION *(CC 52-54)*: I I T (52 53 54)

17. NT FORWARDED FOR EVALUATION *(Date)* *(CC 55-60)*

MO		DAY		YR	
0	6	3	0	7	5
55	56	57	58	59	60

18. COMMENTS

19. PREPARED BY ▶	NAME AND TITLE	SIGNATURE	DATE
20. APPROVED (Center TUO) ▶	NAME	SIGNATURE HCM	DATE 6/30/75

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23280

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United States Patent [19]

Nola

[11] 4,052,648
[45] Oct. 4, 1977

[54] POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

[75] Inventor: Frank J. Nola, Huntsville, Ala.

[73] Assignee: The United States of America as represented by the Administrator of the National Aeronautics and Space Administration, Washington, D.C.

[21] Appl. No.: 706,425

[22] Filed: July 19, 1976

[51] Int. Cl.² H02K 17/04
[52] U.S. Cl. 318/200; 318/227; 318/230
[58] Field of Search .... 318/200, 227, 230, 231, 318/221 R, 216

[56] References Cited

U.S. PATENT DOCUMENTS

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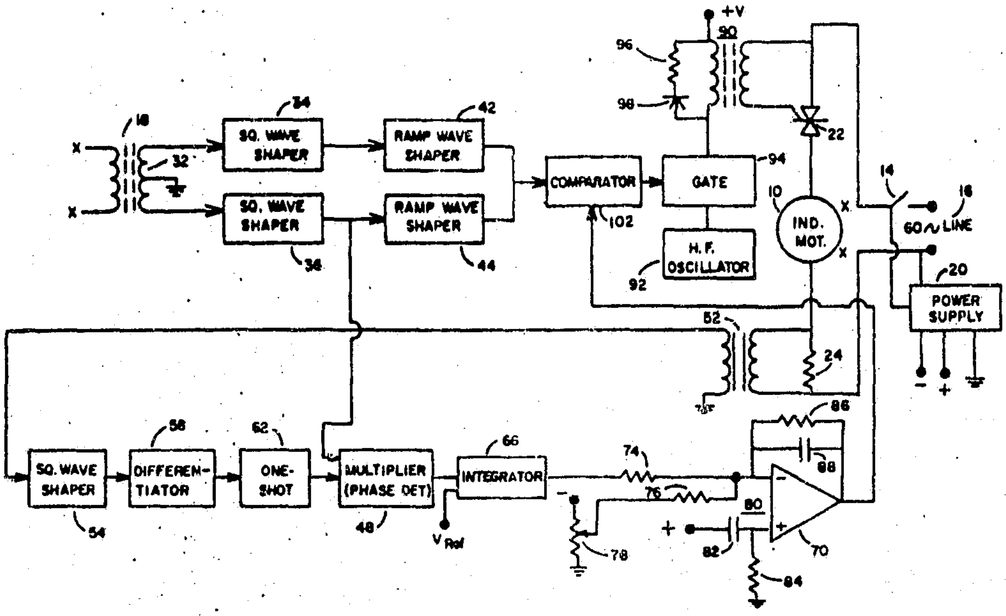
Primary Examiner—Herman J. Hohauser
Attorney, Agent, or Firm—L. D. Wofford, Jr.; George J. Porter; J. R. Manning

[57] ABSTRACT

A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage to thereby provide less power to the motor, as it is less loaded.

5 Claims, 3 Drawing Figures



LICENSED MANUFACTURERS

For "Power Factor Control System for AC Induction Motors", U. S. Patent No. 4,052,648, NASA Case No. MFS-23280

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   Costa Mesa, CA 92626
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   (609) 691-6699

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   Attn: Angelo Pirrello
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    Torrance, CA 90505
    Attn: Fred A. Meyer, Jr.
    (213) 539-5440

Inquiries concerning licensing for commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center, Al 35812.

Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:

current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;

voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;

phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing an output which varies in accordance with the difference in phase between said current and said voltage; and

a control means adapted to be electrically connected in series with each said winding of said motor, and responsive to the output of said phase detection means for varying the duration of "on" time of each cycle of input power to said winding inversely proportional to the difference in phase between said current and said voltage;

whereby an increase in difference between the magnitude of said voltage and the magnitude of load applied to said motor is compensated for by a reduction in power to said motor, generally improving its efficiency.

2. A control system as set forth in claim 1 wherein said current sampling means includes a resistor adapter to be placed in series with a said winding and means for providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein:

said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and

said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

4. A control system as set forth in claim 3 wherein said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

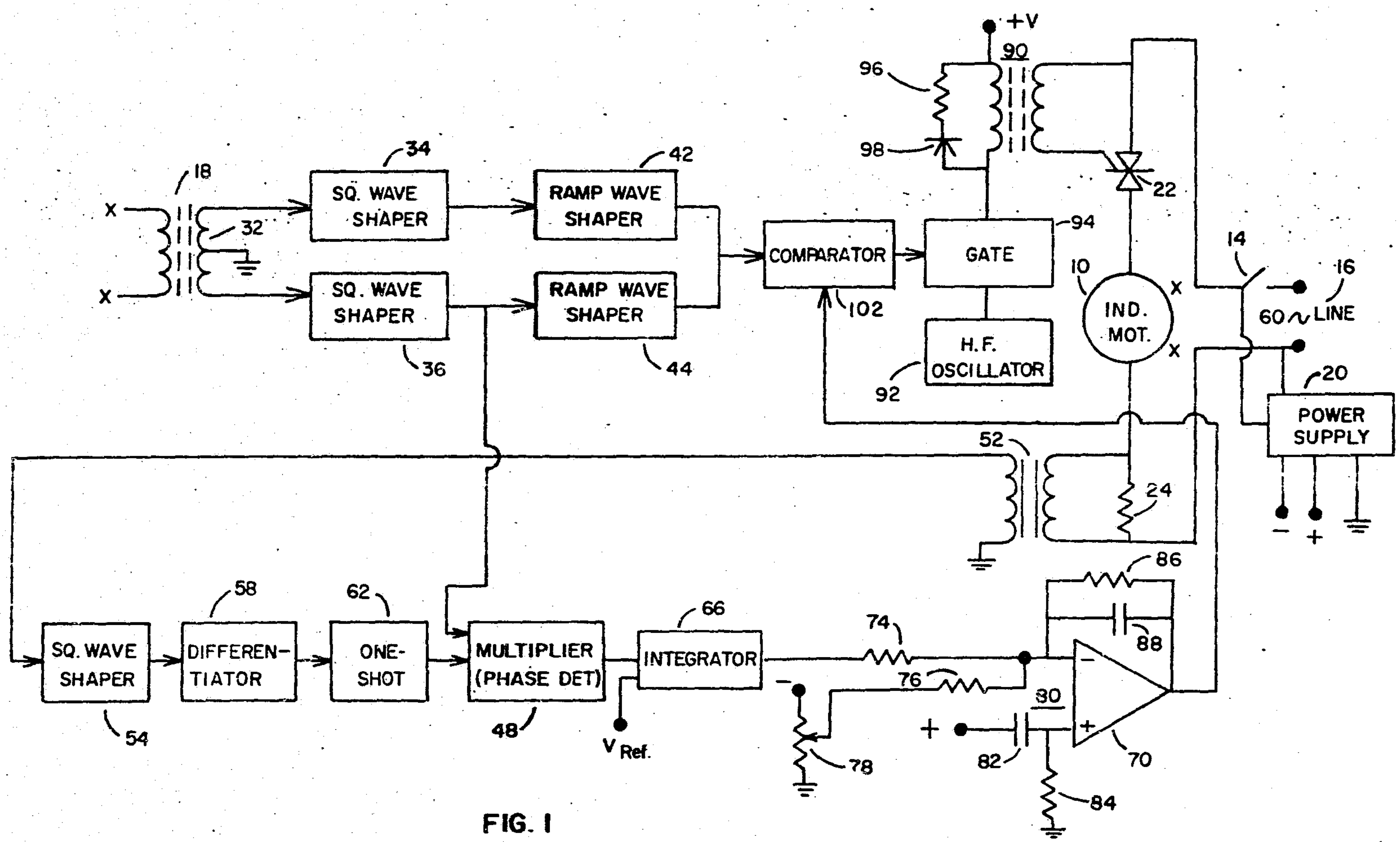
5. A control system as set forth in claim 4 wherein said control means includes:

means responsive to the voltage applied to said winding of said induction motor for providing a saw tooth wave at double the frequency of said voltage;

pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and

switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.

* * * * *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42
18
X
32
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RAMP WAVE SHAPER
SQ. WAVE SHAPER
RAMP WAVE SHAPER
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44
COMPARATOR
102
GATE
94
H.F. OSCILLATOR
92
10
IND. MOT.
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X
14
16
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20
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62
66
74
76
88
80
SQ. WAVE SHAPER
DIFFEREN-TIATOR
ONE-SHOT
MULTIPLIER (PHASE DET)
INTEGRATOR
54
48
V Ref.
78
82
84
70

FIG. 1

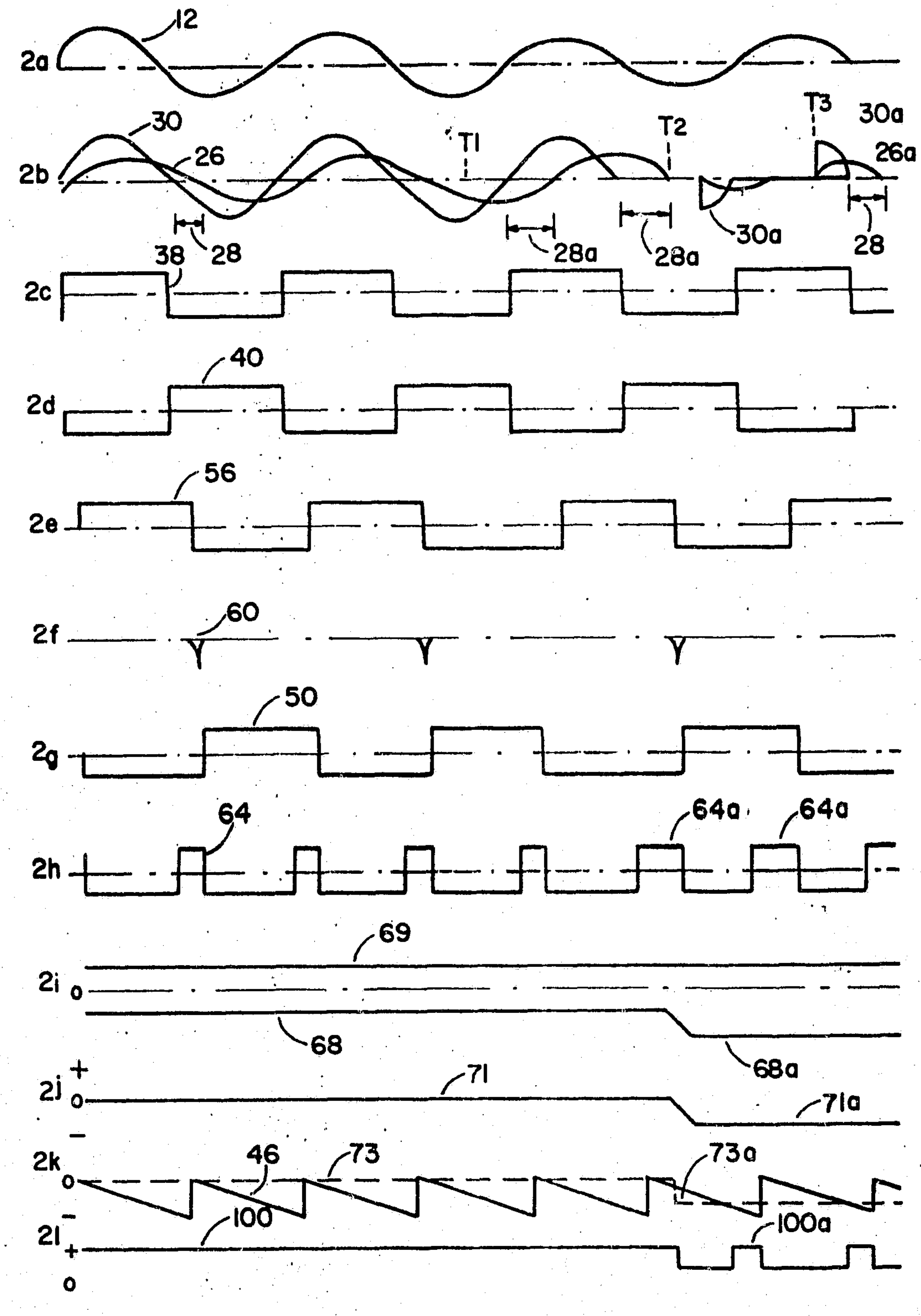
2a
12
2b
30
26
T1
T2
T3
30a
26a
28
38
28a
2c
2d
40
2e
56
2f
60
2g
50
2h
64
64a
2i
69
68
68a
2j
71
71a
2k
46
73
73a
2l
100
100a

FIG. 2

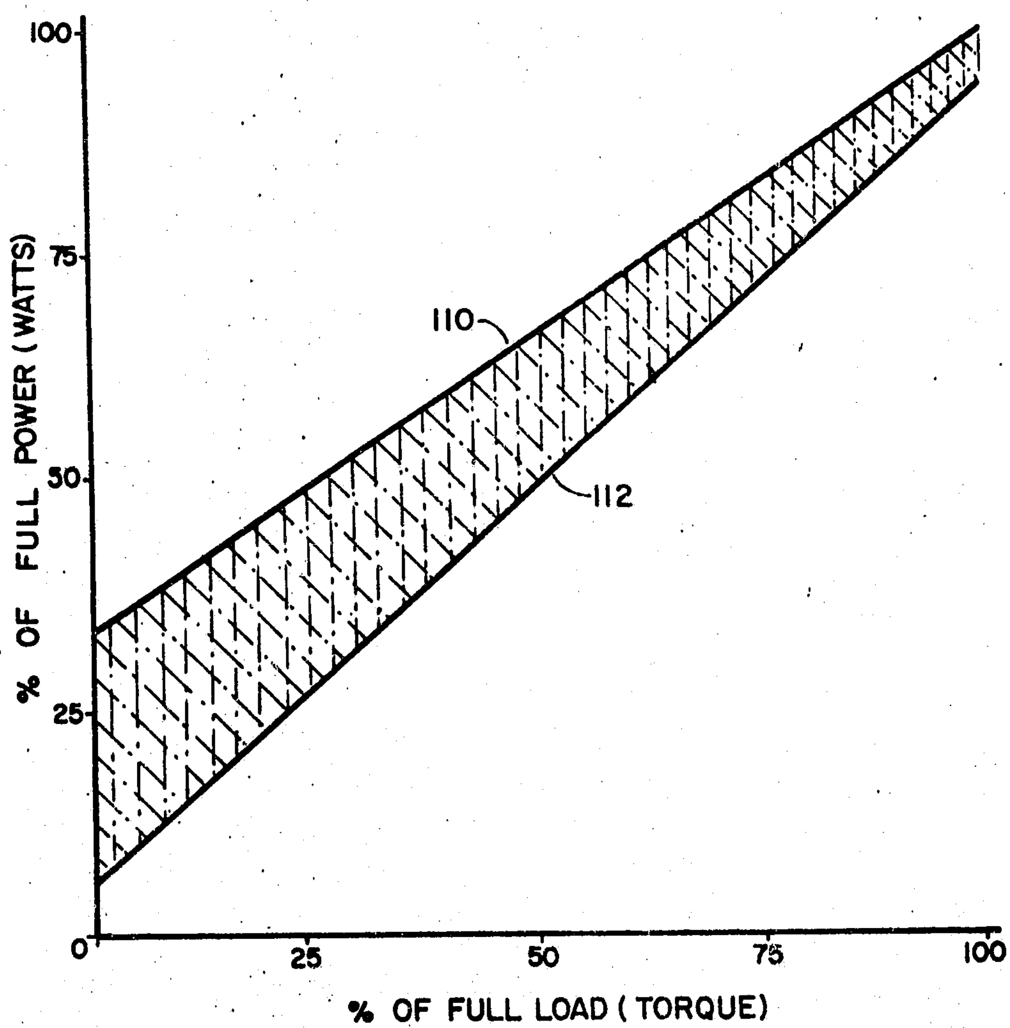
100
75
50
25
0
% OF FULL POWER (WATTS)
110
112
25
50
75
100
% OF FULL LOAD (TORQUE)

FIG. 3

POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art

The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Heretofore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal 115-volt service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention

It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will effect a reduction in power normally provided the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical schematic diagram of an embodiment of the invention.

FIGS. 2*a*–2*l* are waveforms illustrating aspects of operation of the invention.

FIG. 3 is a plot illustrating power drawn by a motor for different states of loading and with and without the control system of this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An AC induction motor 10 is powered by an alternating current voltage 12 (FIG. 2*a*) through switch 14 and connectible at terminals 16. The switched AC power is also applied to transformer 18 and circuit bias power supply 20. Triac 22 is connected in series with motor 10 and is triggered for controlled portions of each half cycle of power input. A small value resistor 24 of 0.010 to 0.020 ohms is connected in series with motor 10 and serves to develop a signal 26 (FIG. 2*b*) which is proportional to the current flow through the motor. FIG. 2*b* illustrates an instantaneous state of operation after initial start-up and with an initial optimum input voltage-load relationship, whereby triac 22 is fully on and where, thereafter, loading is substantially decreased. The initial current-voltage phase lag 28 for such optimum state of operation may vary from motor to motor and would be determined for each motor with which this invention is to be employed. In the present example, initially, optimum phase lag 28 is approximately 30°, and potentiometer 78 is adjusted to provide the zero error output signal for the control of the turn on time of triac 22 to maintain the phase angle of this or another selected value. The occurrence of increased current lag 28*a* at time T_1 depicts a sudden decrease in loading of motor 10. The detection of this is used, as will be further explained, to reduce the average amplitude of input voltage and thereby to effect a commanded, optimum, phase lag.

To further examine the circuitry, transformer 18, having center tap secondary 32, provides oppositely phased inputs to square wave shapers 34 and 36, and the resulting oppositely phased outputs, square wave 38 (from shaper 36) shown in FIG. 2*c* and square wave 40 (from shaper 34) shown in FIG. 2*d*, which are fed to saw tooth or ramp wave shapers 42 and 44, respectively. The outputs of the wave shapers are combined to provide a ramp wave each half cycle of the alternating current input as shown in waveform 46 of FIG. 2*k*. Waveform 38 is also used as a reference signal for the phase of input voltage and is fed to one input of multiplier 48, functioning as a phase detector, to which is also fed a current reference signal 50 shown in FIG. 2*g*. The current reference signal is generated as follows. Current signal 26 (FIG. 2*b*) from resistor 24 is fed to isolation transformer 52 and from it to square wave pulse shaper 54, which provides square wave 56 (FIG. 2*e*). This square wave is differentiated in differentiator 58 to provide spike pulses 60 shown in FIG. 2*f*, and the negative pulses (derived from the trailing edge of square wave 56) are used to trigger one-shot 62, which provides as an output the square waveform 50 shown in FIG. 2*g*. This square waveform commences at a time corresponding to the trailing or zero crossing point of current signal 26 (FIG. 2*b*) and has a duration (determined by the time constant of one-shot 26) corresponding to the length of a half cycle of AC input to the motor. Thus, there is generated a square wave current signal which is of the

same duration as a half wave of voltage waveforms **12**, **38**, and **40**, which is shifted in position proportional to the phase shift difference between current and voltage by virtue of the square wave current responsive signal being commenced at the precise end of (zero crossing) a half cycle of the current signal, which ending in time thus varies as a function of current lag.

Multiplier **48** multiplies voltage waveform **38** as shown in FIG. 2*c* with current waveform **50** shown in FIG. 2*g* to provide the product output waveform **64** shown in FIG. 2*h*. This output is integrated and reversed in sense in integrator **66**. Except for this reversal, the output of integrator **66** would be maximum for conditions of no current lag and minimum for large current lags. To achieve the opposite sense, a reference voltage v_r is fed to one input of integrator **66** where it is negatively summed with the output of multiplier **48**. As a result, the integrated output of integrator **66** is of a value **68**, shown in FIGS. 2*i* and 2*j*, which varies in magnitude directly with phase angle. In other words, the greater the phase angle the greater the system error which is to be corrected. Output **68** (output **68***a* after time T_2) of integrator **66**, which is proportional to the phase angle, is fed to the negative input of operational amplifier **70**. To this same input is also applied an opposite polarity phase angle command voltage **69** (FIG. 2*i*), being applied through resistor **76** from potentiometer **78**. Potentiometer **78** is calibrated to provide an output voltage representative of a desired phase angle to be commanded. Thus, when the system is operating with a commanded phase angle, the output of integrator **66** would be equal and opposite to the command signal from potentiometer **78**, a condition shown by FIG. 2*j* as existing up to time T_2. At this point, by virtue of increased output **64***a* from multiplier **48** because of increase phase shift **28**, the output of integrator **66** increases negatively to a level **68***a*. Thus, there would initially be a net zero error voltage input **71** (FIG. 2*j*) to the negative input terminal of amplifier **70**. Then, for the indicated phase lag in excess of the commanded phase lag, there would be a finite negative error signal **71***a* applied to this input, as shown. When this occurs, amplifier **70**, which is a high gain amplifier, provides an amplified error signal **73***a* (FIG. 2*k*) to comparator **102** to effect such decrease in duty cycle of triac **22** necessary to retain the commanded, optimum, phase angle, in a manner to be described. As shown, this is effected during any interim between times T_2 and T_3.

In order to assure that when motor **10** is first turned on that it will develop maximum torque for a sufficient period to bring the motor up to speed, operation of the control system of this invention is initially delayed. This delay is achieved by delay circuit **80** consisting of capacitor **82** and resistor **84** connected in series between a bias output of power supply **20**, which power supply is energized at the same time as motor **10**, that is, by the closing of switch **14**. Resistor **84** is connected between common ground and the positive input of operational amplifier **70**. With a positive potential signal applied to capacitor **82**, the initial charging current through resistor **84** is of a value sufficient (determined by the time constant of the combination of resistor **84** and capacitor **82**) to override a maximum input applied to the negative terminal for a period of several seconds or longer, depending upon the application. A feedback circuit consisting of resistor **86** and capacitor **88**, connected in parallel between the output of amplifier **70** and the negative input of the amplifier, provides the necessary gain and roll off frequency required for system stability.

Triac **22** is gated "on" by a gating signal coupled from the secondary of transformer **90** across an input of triac **22**. This gating signal is a high frequency signal generated by oscillator **92** and applied to the primary of transformer **90** through gate or electronic switch **94**. Resistor **96** and diode **98** are connected in series across the primary of transformer **90** in order to suppress inductive voltages to a safe level consistent with the semiconductors used. Gate **94** is triggered by pulses **100** (shown in FIG. 2*l*, and which illustrates "on" time of oscillator **92**) from comparator **102** responsive to ramp waveform **46** (FIG. 2*k*) and control input signal **73** (FIG. 2*k*). Output pulses **100** from comparator **102** occur during the interval in which control signal **73** exceeds (is more positive than) ramp voltage **46**. Thus, in the present example, the output of amplifier **70** initially provides a maximum (in a positive direction) output, and pulses **100** would have a **100** percent duty cycle extending over a full ramp period. This would gate "on" oscillator **92** and thereby triac **22** for the entire portion of input voltage cycle as initially shown for voltage waveform **30** in FIG. 2*b*. This, it will be assumed, continues for several seconds and until time T_1, at which time the motor loading decreases to near zero. When this occurs, phase lag **28** will increase to some larger value of phase leg **28***a*, and this will increase, resulting in a shift to the right of current pulse waveform **50** (FIG. 2*g*), which in turn will provide an increased width output pulse **64** from multiplier **48** (at time T_2). In turn, this will provide an increase in the output of integrator **66** and input to amplifier **70**, which will change from a zero level (level **71**) to a discrete negative level (level **71***a*), as shown in FIG. 2*j*. As a result, amplifier **70** will provide an amplified, less positive, output error signal **73***a* commencing at time T_2, as shown in FIG. 2*k*. When this occurs, comparator **102** provides a reduced width pulse **100***a* to gate **94**, and it triggers "on" triac **22** for like decreased width periods to produce a change in input voltage, changing (at time T_3) from that shown by waveform **30** to that shown by waveform **30***a*.

Thus, motor input voltage waveform **30** goes through a transition during the period of T_1 to T_3, having an initial phase lag **28** to an increased phase lag **28***a* and then back to the commanded phase lag **28**, shifting from full width cycles **30** to extremely short width duration input cycles **30***a*. The shift in input voltage has been that necessary to re-establish the commanded currentvoltage phase lag, power factor, to thus maintain an optimum power input to motor **10**. Had this not been done, the phase angle would have increased substantially, and thus the power factor would have decreased substantially, resulting in a significant waste of power.

FIG. 3 plots the percent of full power applied to motor **10** versus percent of full load, or torque, and line **112** illustrates a case where the control system of this invention is employed. Line **110** illustrates a case where it is not. The hatched difference between the lines is indicative of the power saved by employment of the invention.

While the invention illustrated herein is shown as being usable with a single phase device, it may be connected in circuit with each phase of a multi-stage induction motor. Thus, in the case of a Wye-connected three phase motor, three of the control systems illustrated in FIG. 1 will be employed, one being connected in each of the three phases with each referenced to ground (the

Wye of the motor). In the case of a delta-connected motor, it will be necessary to place a triac and sampling resistor in series with each winding of the motor, and the voltage reference would be obtained for that control device across the two input power leads to that winding.

Having thus described my invention, what is claimed is:

1. A power factor control system for an AC induction motor comprising:

current sampling means including means adapted to be placed in circuit with each phase winding of a said motor for providing an AC output signal in phase with the current through said winding;

voltage sampling means adapted to sense the voltage of an electrical input applied to said winding and for providing an output signal in phase with said voltage across said winding;

phase detection means responsive to the outputs of said current sampling means and said voltage sampling means for providing an output which varies in accordance with the difference in phase between said current and said voltage; and

a control means adapted to be electrically connected in series with each said winding of said motor, and responsive to the output of said phase detection means for varying the duration of "on" time of each cycle of input power to said winding inversely proportional to the difference in phase between said current and said voltage;

whereby an increase in difference between the magnitude of said voltage and the magnitude of load applied to said motor is compensated for by a reduction in power to said motor, generally improving its efficiency.

2. A control system as set forth in claim 1 wherein said current sampling means includes a resistor adapter to be placed in series with a said winding and means for providing a signal proportional to the voltage across said resistor.

3. A control system as set forth in claim 2 wherein:

said voltage sampling means comprises means for providing a square wave pulse output at the frequency of the voltage applied to said winding; and

said current sampling means comprising means responsive to said voltage from said resistor for providing square wave output pulses of the width and height of said pulses from said voltage sampling means, and each pulse having an edge coinciding with the zero crossing of said voltage across said resistor.

4. A control system as set forth in claim 3 wherein said phase detection means includes means for multiplying the magnitudes of said square wave pulses from said voltage and current sampling means.

5. A control system as set forth in claim 4 wherein said control means includes:

means responsive to the voltage applied to said winding of said induction motor for providing a saw tooth wave at double the frequency of said voltage;

pulse generating means responsive to a comparison of said saw tooth voltage and said output of said phase detection means for providing output pulse bursts of high frequency signal in which the width of the pulse bursts is directly proportional to the time in which said output of said phase detection means differs in a selected direction from the value of said saw tooth wave; and

switching means adapted to be placed in circuit with said winding of said motor and responsive to said pulse generating means for varying the width of half cycles of power applied to said winding of said motor in accordance with the width of said bursts of high frequency signal.

* * * * *

ORGANIZATION:

ELECTRONICS AND CONTROL LABORATORY

MARSHALL SPACE FLIGHT CENTER

POWER FACTOR CONTROLLER

NAME: FRANK NOLA

DATE: JUNE 1978

BACKGROUND

0 ORGANIZATION

GUIDANCE, CONTROL AND INSTRUMENTATION DIVISION
ELECTRONICS AND SERVO ANALYSIS BRANCH

0 BECAME INVOLVED THROUGH MSFC'S SOLAR HEATING AND COOLING PROGRAM

0 INITIAL WORK DONE IN APRIL 1975

0 NOTIFIED IN MAY 1977 PATENT WOULD BE ISSUED

0 CONCEPT VERIFIED BY AUBURN UNIVERSITY

0 PATENT ISSUED OCTOBER 1977

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
ELECTRONICS AND CONTROL LABORATORY	POWER FACTOR CONTROLLER	FRANK NOLA
		DATE: JUNE 1978

ENERGY IN MOTORS

0 STUDY BY A.D. LITTLE CORP. INDICATES ABOUT TWO THIRDS OF ELECTRICAL ENERGY GENERATED IS FOR MOTORS.

0 THIS AMOUNTS TO ABOUT 1100 BILLION KWHR PER YEAR

0 10 PERCENT IS IN HOMES AND 90 PERCENT IN INDUSTRY

0 REQUIRES THE EQUIVALENT OF 6,000,000 BARRELS OF OIL PER DAY

0 EACH PERCENT ENERGY TO MOTORS IS REDUCED SAVES THE EQUIVALENT OF 60,000 BARRELS OF OIL PER DAY

FILE NO.

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		DATE: JUNE 1978

INDUCTION MOTORS

- 0 DESIGNED FOR CONSTANT VOLTAGE AND CONSTANT FREQUENCY
- 0 RUN AT ESSENTIALLY CONSTANT SPEED REGARDLESS OF LOAD
- 0 CURRENT REMAINS HIGH AT NO LOAD CREATING LARGE INTERNAL LOSSES
- 0 NO LOAD CURRENT IN SINGLE PHASE MOTORS IS 70 TO 90% OF RATED LOAD CURRENT
- 0 NO LOAD CURRENT IN 3 PHASE MOTORS IS 50 TO 60% OF RATED LOAD CURRENT
- 0 PHASE ANGLE BETWEEN VOLTAGE AND CURRENT INCREASES WITH DECREASING LOAD

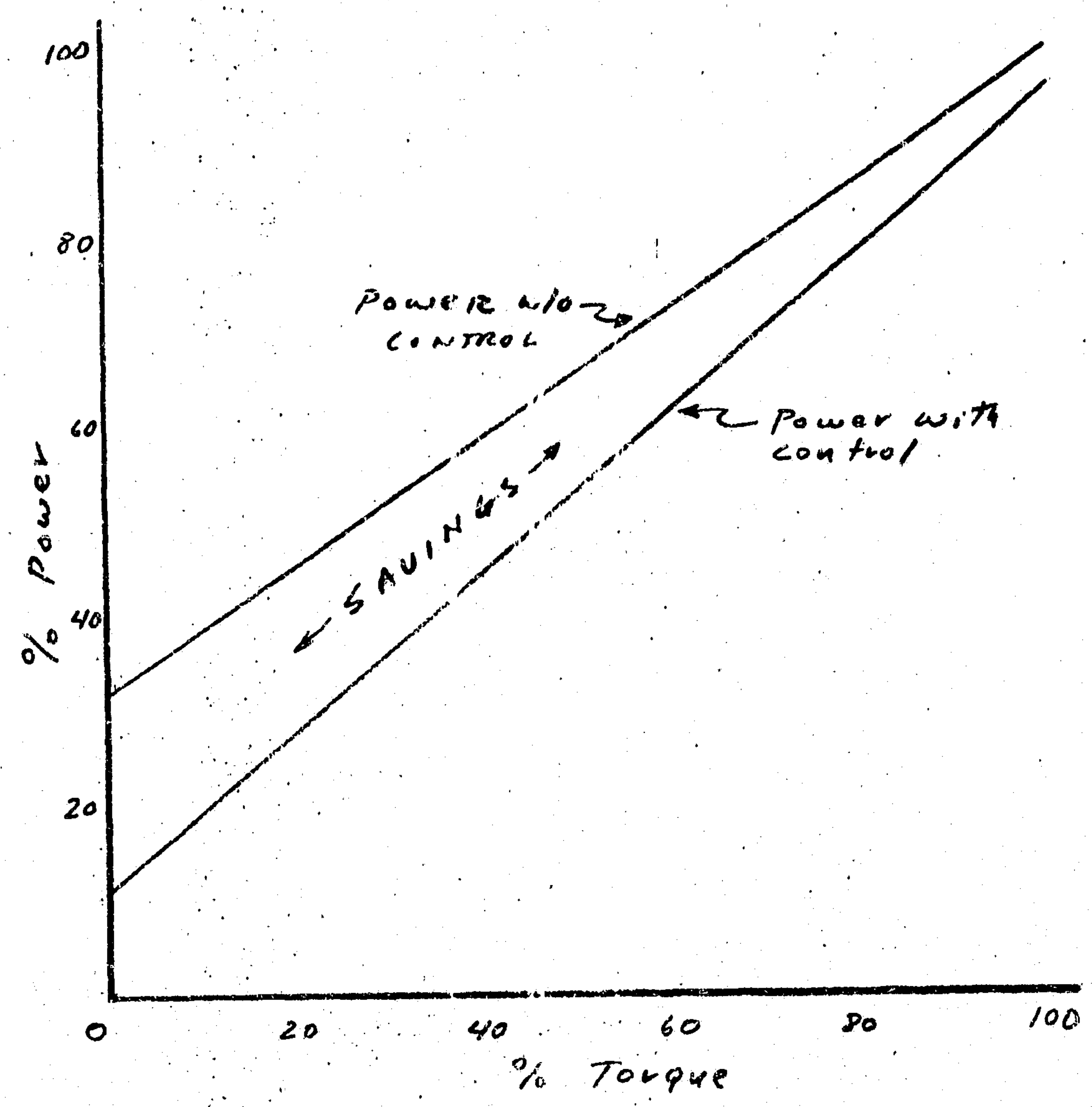
ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
ELECTRONICS AND CONTROL LABORATORY	POWER FACTOR CONTROLLER	FRANK NOLA
		DATE: JUNE 1978

CONCEPT

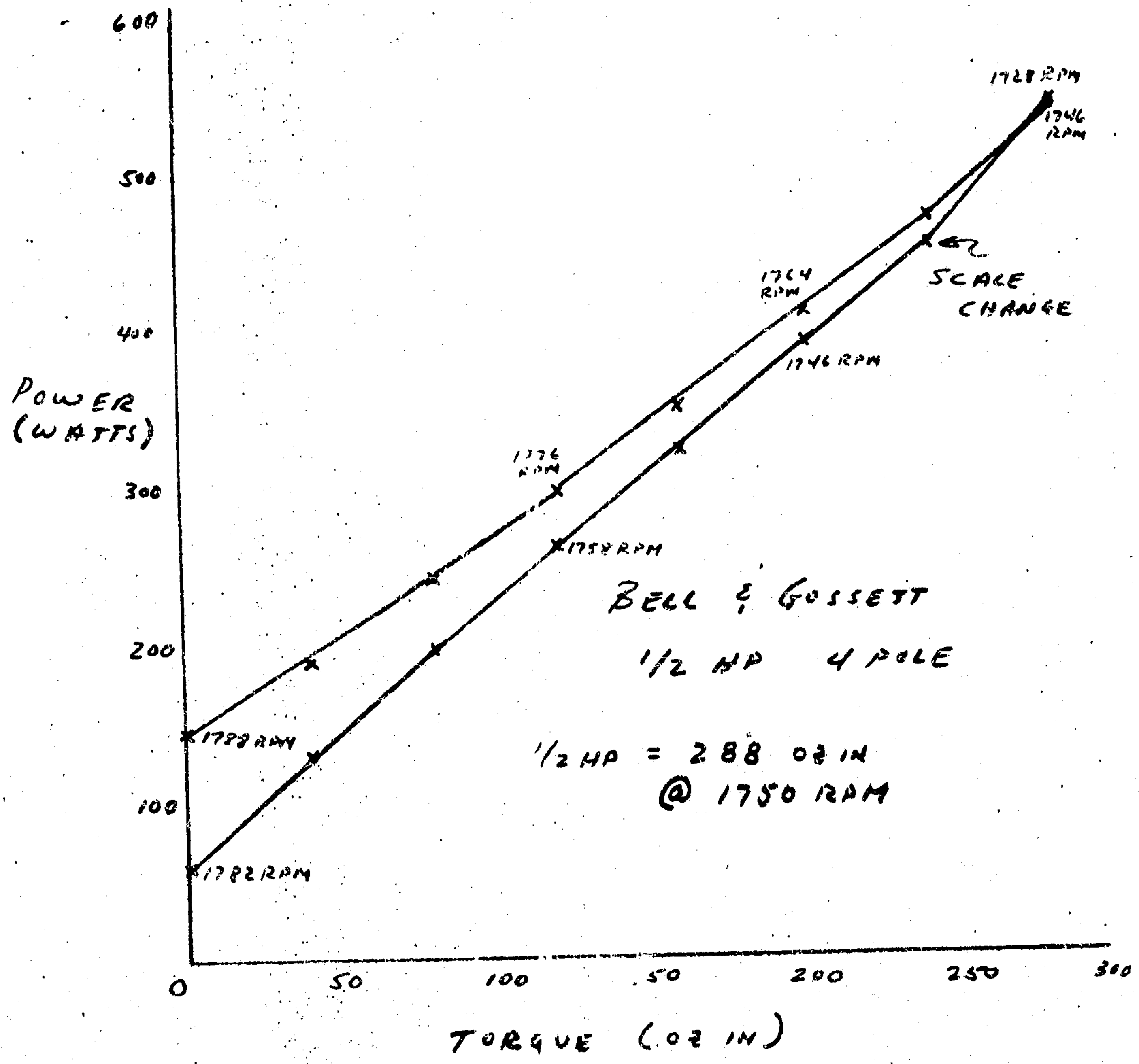
- 0 THE DEVICE SENSES THE LINE VOLTAGE AND LINE CURRENT
- 0 PRODUCES A VOLTAGE PROPORTIONAL (INVERSELY) TO PHASE ANGLE BETWEEN VOLTAGE AND CURRENT.
- 0 COMPARES THIS VOLTAGE WITH A COMMANDED REFERENCE VOLTAGE INDICATIVE OF A DESIRED PHASE ANGLE.
- 0 DIFFERENCE IS AN ERROR VOLTAGE WHICH BIASES A RAMP THAT IS IN SYNC WITH THE 60 HZ LINE VOLTAGE
- 0 RAMP AND ERROR ARE COMPARED IN A ZERO CROSSING DETECTOR. (ZCD)
- 0 THE OUTPUT OF THE ZCD FORMS THE FIRING PULSE FOR TURNING ON A TRIAC IN SERIES WITH THE MOTOR.
- 0 NO MODIFICATION REQUIRED FOR SINGLE PHASE MOTORS
- 0 WYE CONNECTED MOTORS REQUIRE CONNECTION TO WYE POINT

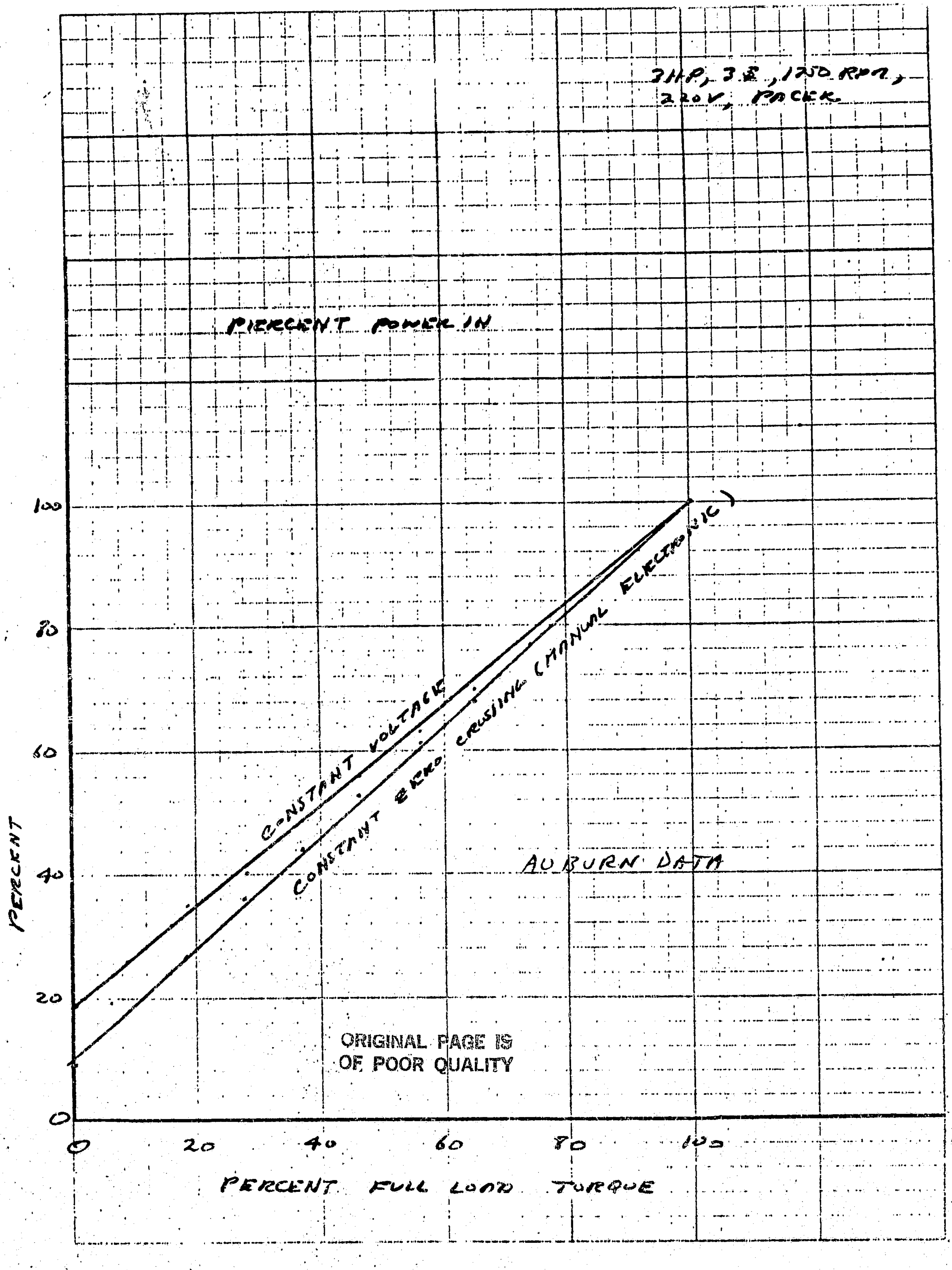
FILE NO.

ORIGINAL PAGE IS
OF POOR QUALITY

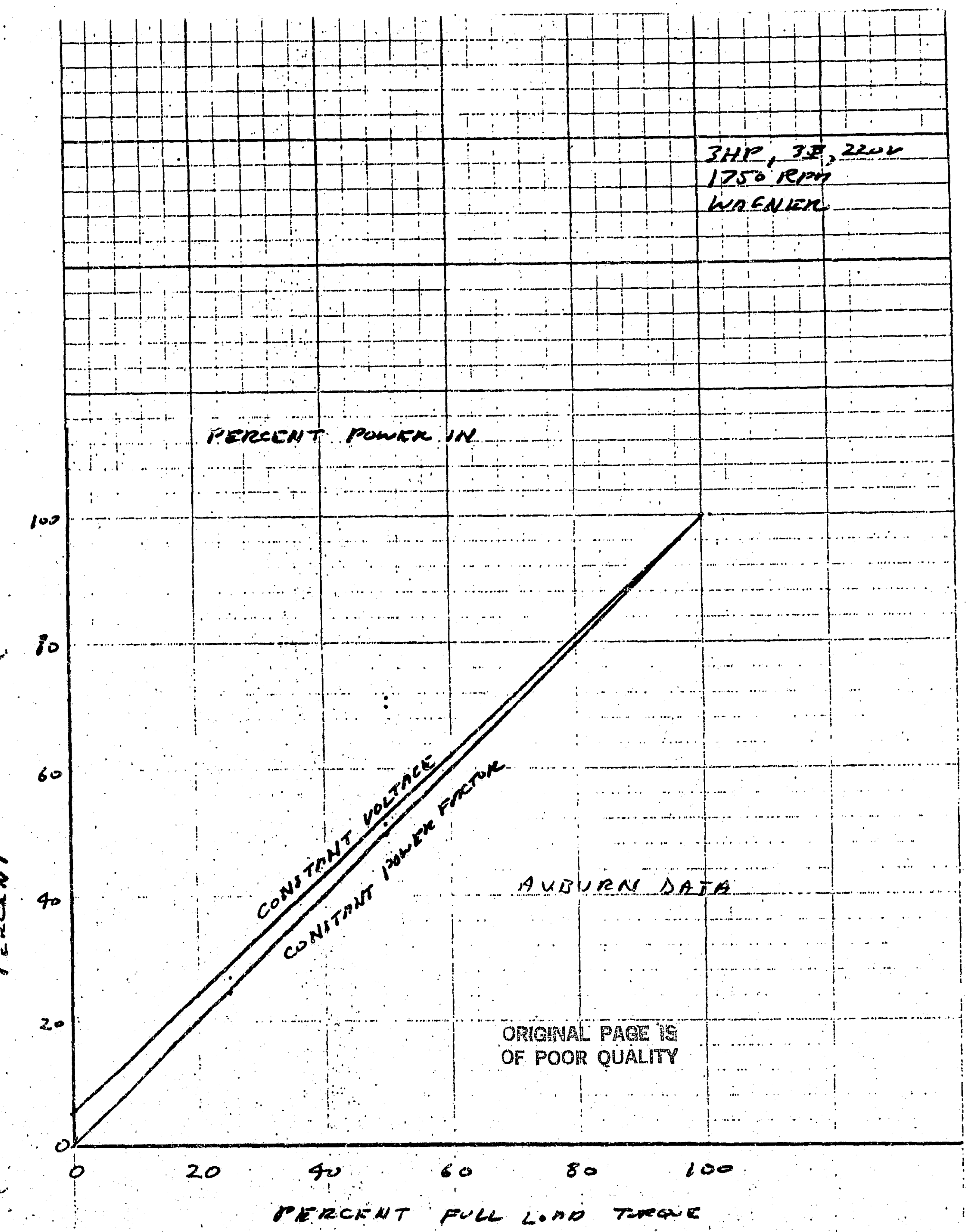


TYPICAL POWER SAVINGS FOR
SINGLE PHASE MOTOR


600
500
400
300
200
100
POWER (WATTS)
0
50
100
150
200
250
300
TORQUE (OZ IN)
1788 RPM
1782 RPM
1776 RPM
1758 RPM
1764 RPM
1746 RPM
1728 RPM
1746 RPM
SCALE CHANGE
BELL & GOSSETT
1/2 HP 4 POLE
1/2 HP = 288 OZ IN
@ 1750 RPM



3HP, 3Φ, 1750 RPM,
220V, PACER
PERCENT POWER IN
CONSTANT VOLTAGE
CONSTANT ZERO CROSSING (MANUAL ELECTRONIC)
AUBURN DATA
PERCENT
0
20
40
60
80
100
PERCENT FULL LOAD TORQUE
ORIGINAL PAGE IS
OF POOR QUALITY



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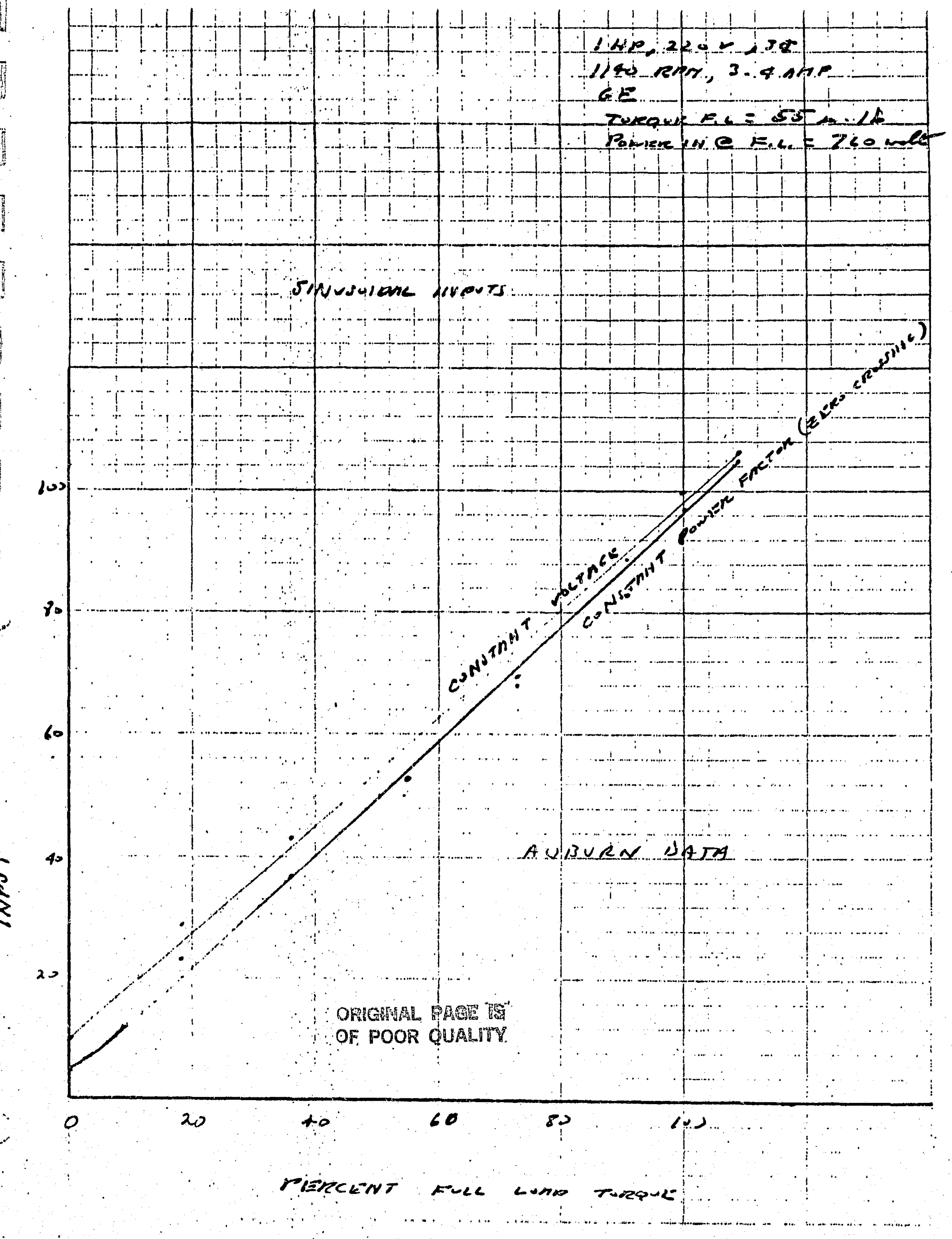
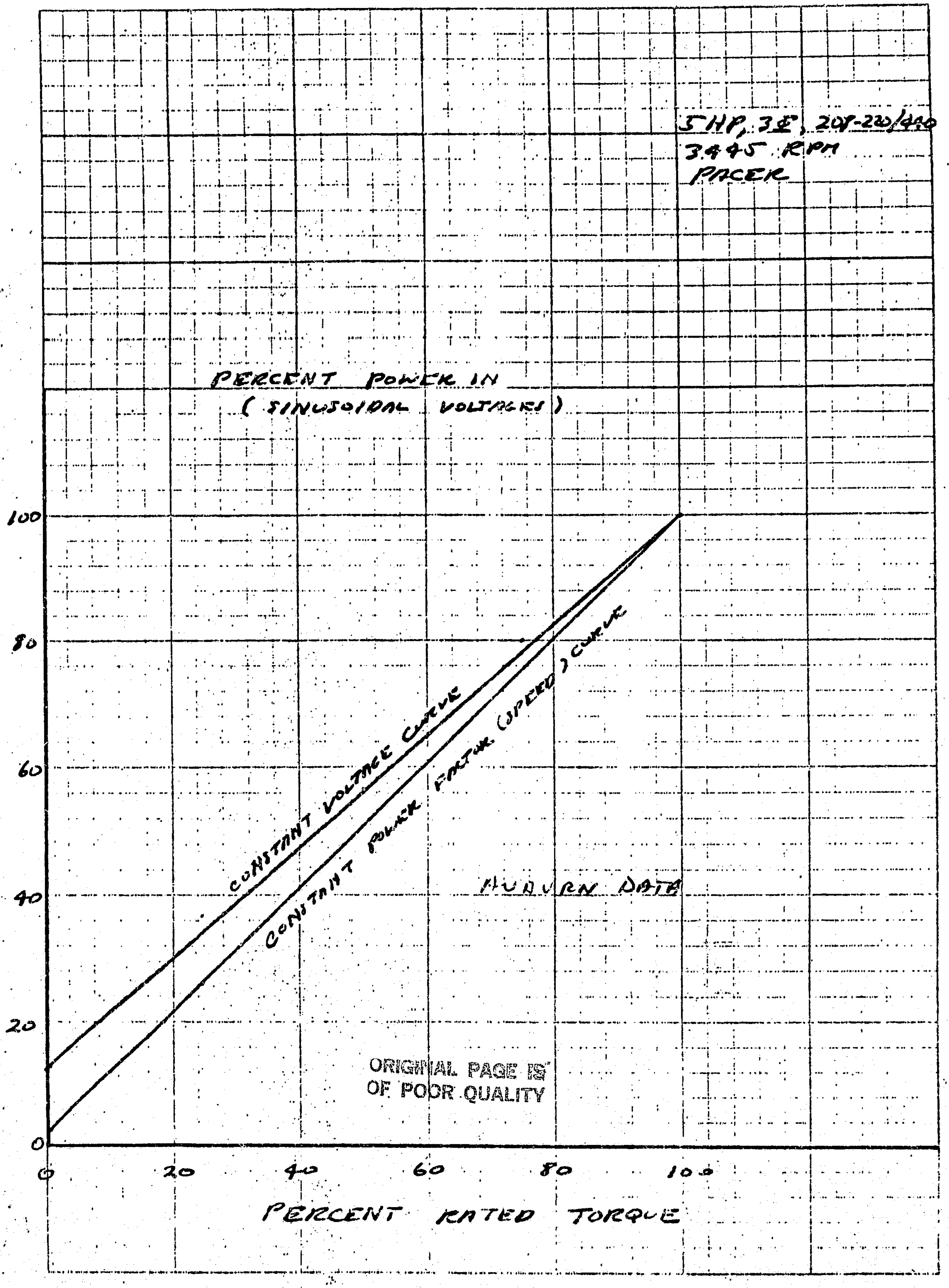

1 HP, 220 V, 3Φ
1140 RPM, 3.4 AMP
GE
TORQUE F.L = 55 in.lb
POWER IN @ F.L = 760 watt
SINUSOIDAL INPUTS
CONSTANT VOLTAGE
CONSTANT POWER FACTOR (ZERO CROSSING)
AUBURN DATA
INPUT
0
20
40
60
80
100
PERCENT FULL LOAD TORQUE
ORIGINAL PAGE IS OF POOR QUALITY



5 HP, 3Φ, 208-220/440
3445 RPM
PACER
PERCENT POWER IN
(SINUSOIDAL VOLTAGES)
100
80
60
40
20
0
CONSTANT VOLTAGE CURVE
CONSTANT POWER FACTOR (SPEED) CURVE
AUBURN DATA
0
20
40
60
80
100
PERCENT RATED TORQUE

PERCENT SAVINGS AT VARIOUS LOADS

LOAD → CONDITION	FULL LOAD	80%	60%	40%	20%	NO LOAD
3 HP WAGNER	0%	1.5%	4%	7%	15%	60%
5 HP PACER	0%	4%	8%	15%	30%	65%
1 HP GE	1.5%	4%	7%	10%	25%	50%
3 HP PACER	0%	2.5%	6%	10%	20%	50%

TABULATED FROM AUBURN DATA

ALL 3 ϕ MOTORS

MANUAL PHASE CONTROL

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
ELECTRONICS AND CONTROL LABORATORY	POWER FACTOR CONTROLLER	FRANK NOLA
		DATE: JUNE 1978

TEXTILE MILL APPLICATION

0 BREADBOARD CONTROLLER WHICH WAS GOVERMENT FURNISHED TO AUBURN WAS TESTED IN A TEXTILE MILL.

0 MILL HAS 3700 SEWING MACHINES

0 EACH MACHINE HAS A 1/2 HP AMCO 3-PHASE MOTOR WITH WYE CONNECTION EXTERNAL TO MOTOR FOR CONNECTING TO LIGHT.

0 PLANT RESEARCH ENGINEER INDICATED THIS IS AN INDUSTRY STANDARD MOTOR SELECTED FOR HIGH PERFORMANCE AND RELIABILITY AND ESTIMATES 90% USEAGE IN TEXTILE INDUSTRY. COST $80 WITH CLUTCH.

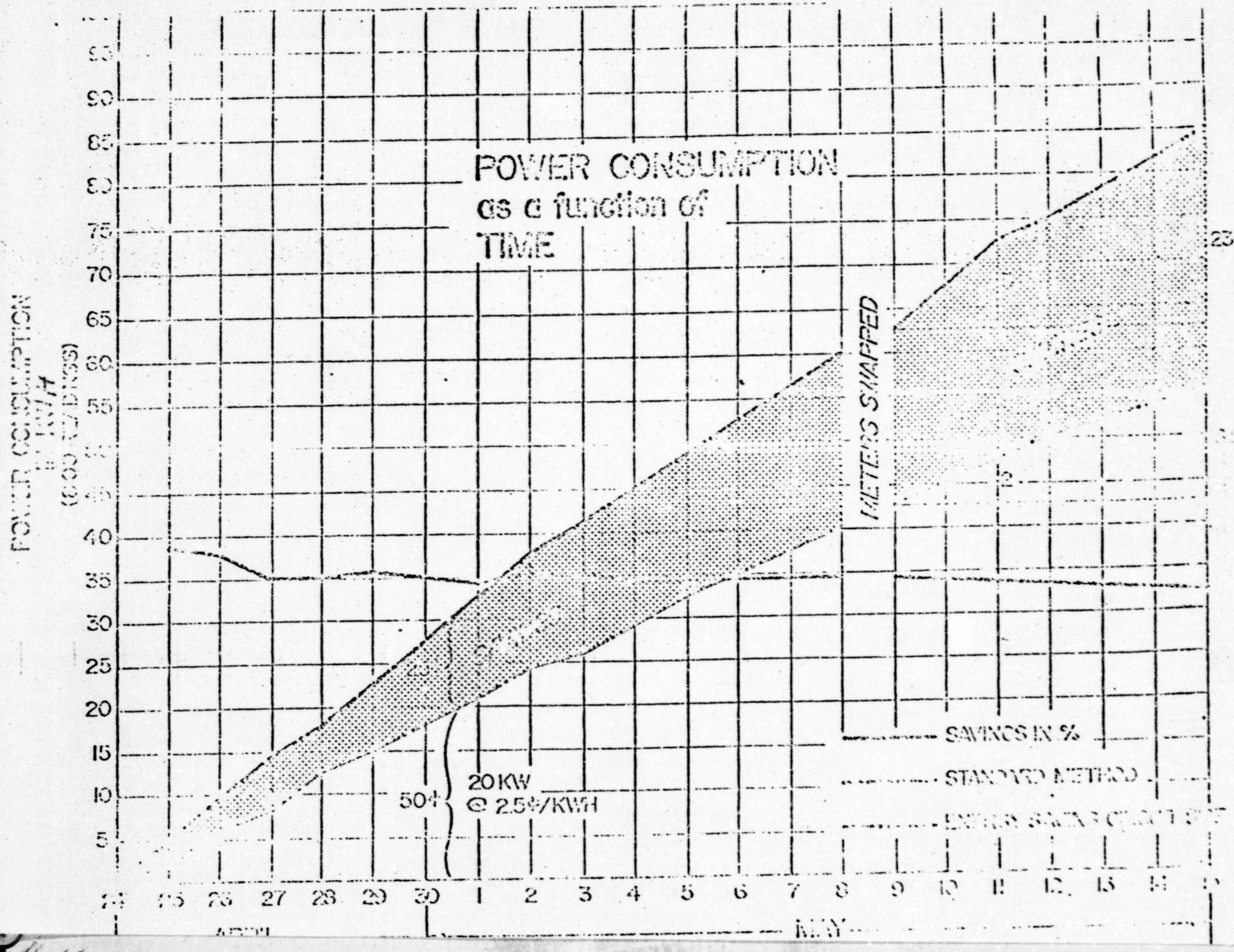
0 CONTROLLER WAS CONNECTED TO ONE MACHINE. THIS MACHINE AND A SECOND MACHINE WERE INSTRUMENTED FOR MEASURING POWER CONSUMPTION.

0 A TYPICAL 20 DUTY CYCLE WAS SIMULATED FOR BOTH MACHINES.

0 BOTH MACHINES RAN 24 HRS A DAY FOR 21 DAYS

0 MACHINE EQUIPPED WITH CONTROLLER INDICATED ABOUT 33% LESS POWER CONSUMPTION

FIGURE NO. 3


POWER CONSUMPTION
as a function of
TIME
POWER CONSUMPTION
KWH
METERS SWAPPED
20 KW
@ 2.5¢/KWH
50¢
23.9
SAVINGS IN %
APRIL
MAY

ORGANIZATION: ELECTRONICS AND CONTROL LABORATORY	MARSHALL SPACE FLIGHT CENTER POWER FACTOR CONTROLLER	NAME: FRANK NOLA DATE: JUNE 1978

TO BE DETERMINED

- O POTENTIAL THIS CIRCUIT HAS FOR SAVING ENERGY
- O COST TO PRODUCE THE DEVICE - BOTH SINGLE AND 3 PHASE
- O COST EFFECTIVENESS OF APPLYING THE DEVICE
- O CAN THE DEVICE AID IN CUTTING COSTS CHARGED FOR A POOR POWER FACTOR? CAN IT REPLACE CAPACITORS AND SYNCHRONOUS MOTORS USED FOR CORRECTION.
- O IN CERTAIN APPLICATIONS CAN THE DEVICE DOUBLE AS THE POWER CONTACTOR FOR THE MOTOR?
- O CAN THE DEVICE SERVE AS A MEANS OF LIMITING STARTING INRUSH CURRENT IN LARGE MOTORS?
- O POTENTIAL FOR REDUCING AIR CONDITIONING COSTS.
- O HOW SERIOUS IS THE PROBLEM OF CONNECTING TO THE WYE POINT OF 3 PHASE WYE MOTOR?
- O IS THE WYE POINT AVAILABLE IN LARGER MOTORS?
- O EFFECT ON UTILITIES DISTRIBUTION SYSTEM
- O IS THE SAVINGS TO THE UTILITY COMPANY SIGNIFICANT?
- O STABILITY NEEDS TO BE ANALYZED
- O ABILITY TO RESPOND TO STEP TYPE LOADING NEEDS TO BE STUDIED AND IMPROVED
- O IN SOME CASES THE CAPACITOR REQUIRED FOR STABILITY NEEDS TO BE LARGER THAN THAT REQUIRED FOR FILTERING. THIS SLOWS THE RESPONSE.

FILE NO.

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER	NAME:
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		DATE: JUNE 1978

TO BE DETERMINED (CONT'D)

- 0 IN SOME CASES THERE HAS BEEN A MISFIRING OF THE TRIAC
- 0 BALANCING OF THE 3 ERROR SIGNALS IN 3 PHASE MOTORS MAY BE A PROBLEM
- 0 POSSIBILITY OF ELIMINATING THE NEED FOR CONNECTING TO THE WYE POINT NEEDS INVESTIGATING

The patent is somewhat difficult to read and the circuitry it describes, we have since learned, is more complex than required.

[illegible] ... is better [illegible]

[illegible] is unloaded or partially loaded. Six single phase motors we tested showed unloaded current to be about 90% of the rated load current. Four three-phase motors (5 Hp down) showed the no load current to be about 50 to 60% of rated load current. These currents cause heat losses in the motor and in the utilities distribution system. Large users of motors with cyclic loads are often charged for a poor power factor.

Since the current remains high in an unloaded motor, the phase angle between voltage and current shifts with load. Typically the current may lag the voltage 80° in an unloaded motor and 30° when loaded. The power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference of the two produces an error signal which biases a ramp voltage that is in sync with the 60 Hz line voltage. The intersection of the ramp and the error voltages are detected by a squaring amplifier whose output provides the timing for turning on a triac (or SCR's) in the motor line.

Thus the "on" time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the attached timing diagram.

The phase angle shown as θ in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

In the circuit, amplifiers A1 and A2 produce a square wave and its inverse which are in sync with the zero crossings of the voltage. These are E and $\bar{E}$ in the timing diagram.

The current waveform which is sensed by the resistor (R20) transformer (T3) combination or by a current transformer is squared by amplifiers A5 and A6 to produce I and I'. $\bar{E}$ is AND'ed with I and E is AND'ed with I'. These two outputs are OR'ed to produce the voltage which is representative of the phase angle between voltage and current.

This voltage is filtered and summed with the command voltage in amplifier A7. The output is the system error signal and is compared with the ramp voltage in Amplifier A3. The error is shown superimposed on the

ORIGINAL PAGE IS
OF POOR QUALITY

The patent is somewhat difficult to read and the circuitry it describes, we have since learned, is more complex than required.

[illegible] is better.

[illegible] motor is unloaded or partially loaded. Six single phase motors we tested showed unloaded current to be about 90% of the rated load current. Four three-phase motors (5 Hp down) showed the no load current to be about 50 to 60% of rated load current. These currents cause heat losses in the motor and in the utilities distribution system. Large users of motors with cyclic loads are often charged for a poor power factor.

Since the current remains high in an unloaded motor, the phase angle between voltage and current shifts with load. Typically the current may lag the voltage 80° in an unloaded motor and 30° when loaded. The power factor control circuit continuously monitors the phase angle between the voltage and current and produces a voltage proportional to the phase angle. This voltage is summed with a fixed reference voltage which is indicative of a desired phase angle. The difference of the two produces an error signal which biases a ramp voltage that is in sync with the 60 Hz line voltage. The intersection of the ramp and the error voltages are detected by a squaring amplifier whose output provides the timing for turning on a triac (or SCR's) in the motor line.

Thus the "on" time of the triac varies with the load and varies the voltage to force the phase angle to remain at the commanded value.

With the system in control, typical motor voltage and current waveforms are as shown in the attached timing diagram.

The phase angle shown as θ in the timing diagram is measured by detecting the time between the zero crossings of the voltage and the zero value of the trailing edge of the current.

In the circuit, amplifiers A1 and A2 produce a square wave and its inverse which are in sync with the zero crossings of the voltage. These are E and $\bar{E}$ in the timing diagram.

The current waveform which is sensed by the resistor (R20) transformer (T3) combination or by a current transformer is squared by amplifiers A5 and A6 to produce I and I'. $\bar{E}$ is AND'ed with I and E is AND'ed with I'. These two outputs are OR'ed to produce the voltage which is representative of the phase angle between voltage and current.

This voltage is filtered and summed with the command voltage in amplifier A7. The output is the system error signal and is compared with the ramp voltage in Amplifier A3. The error is shown superimposed on the

ramp in the timing diagram. The intersection of the error voltage and the sloped portion of the ramp form the turn on time for the triac. The triac remains on until the current passes through zero for each half cycle. C7 and R27 are a starting override that commands full voltage for starting the motor.

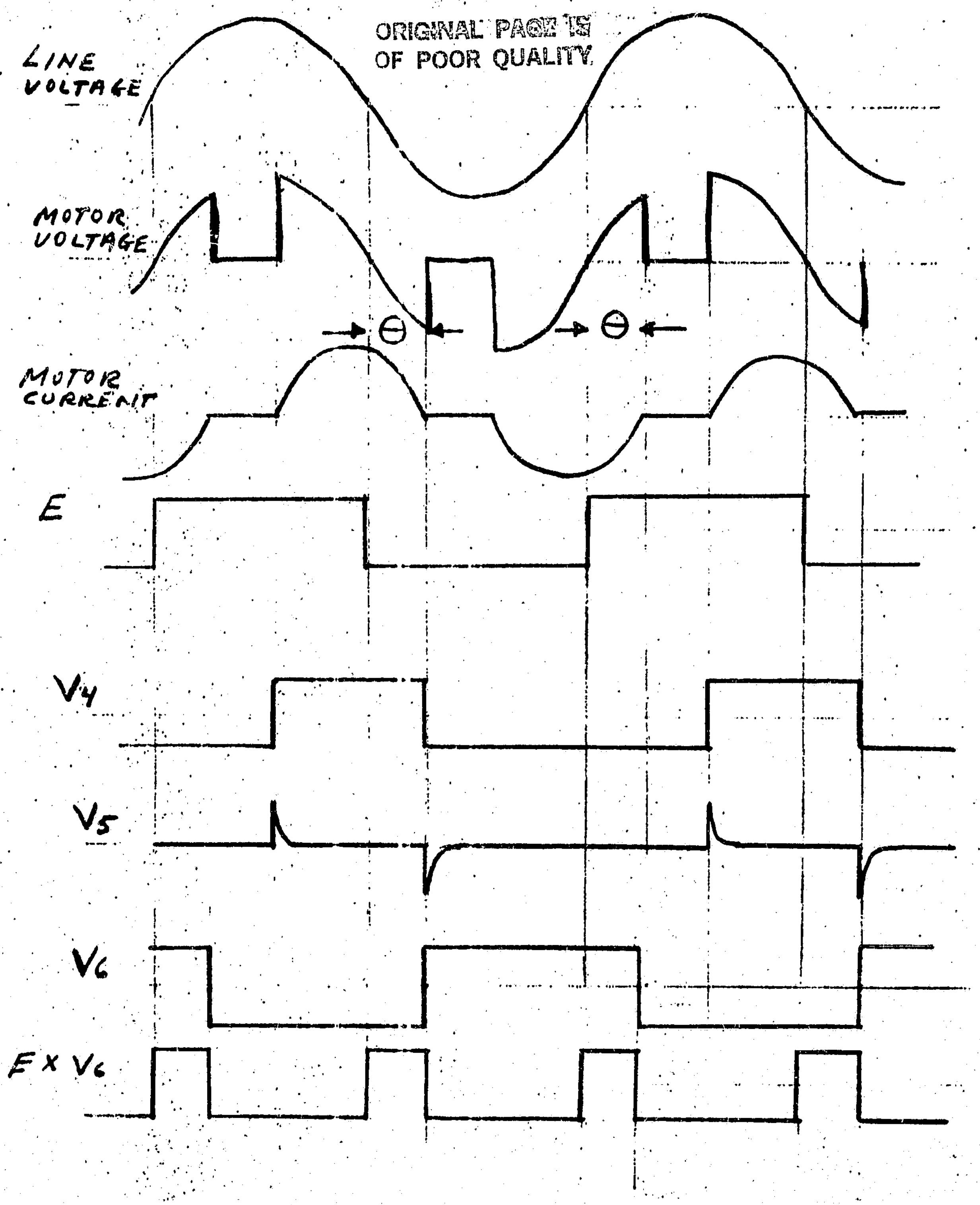
The circuit described by the patent and shown in the tech brief functions in a similar manner. The current waveform is squared only once as shown by I in the timing diagram. The falling edge of the squared pulse contains the phase angle information. This waveform is differentiated to form trigger pulses which are fed to a one shot. The one shot is sensitive only to the negative trigger (falling edge) and the transition time is set to be equal to a half cycle of 60 Hz. Thus a symmetrical square wave is produced which contains the phase shift information. This square wave is fed to one input of a multiplier. The line voltage is squared and fed to the second input. The output of the multiplier is similar to the ORed voltage shown in the timing diagram. The remainder of the circuit functions identical to that previously described. Amplifier A8 shown in the tech brief and called integrator (66) in the patent is not required and has been eliminated.

Most of the testing of the power factor control circuit has been done with motors loaded by a dynamometer. The response time of the dynamometer is a few tenths of a second. The stability of the system for step type loading needs investigating. The response time of this circuit is limited by the filter time constant required to smooth the phase angle voltage (output of U.C.).

Our test has shown that the slow down of a fully loaded motor with this circuit in control is less than 2%.

Single phase motors require no modifications to apply this controller. With wye connected 3-phase motors, we have found it necessary to connect to the wye internal to the motor. A triac with its firing circuitry is placed in series with each phase of the motor. The phase angle is sensed in only one phase and the error signal controls the 3 phases. To our knowledge the circuit has not been tried with a delta connected motor. We believe it will be necessary to place the triac in series with each winding inside the delta. Two voltage delta motors have all the necessary leads external to the motor so that no internal modification would be required.

We believe that in certain applications, the cost effectiveness of applying this controller could be enhanced by having the circuit (with slight modifications) serve also as the on-off contactor for a motor or as a means of limiting starting inrush current in larger motors.


LINE VOLTAGE
MOTOR VOLTAGE
Θ
Θ
MOTOR CURRENT
E
V4
V5
V6
E × V6

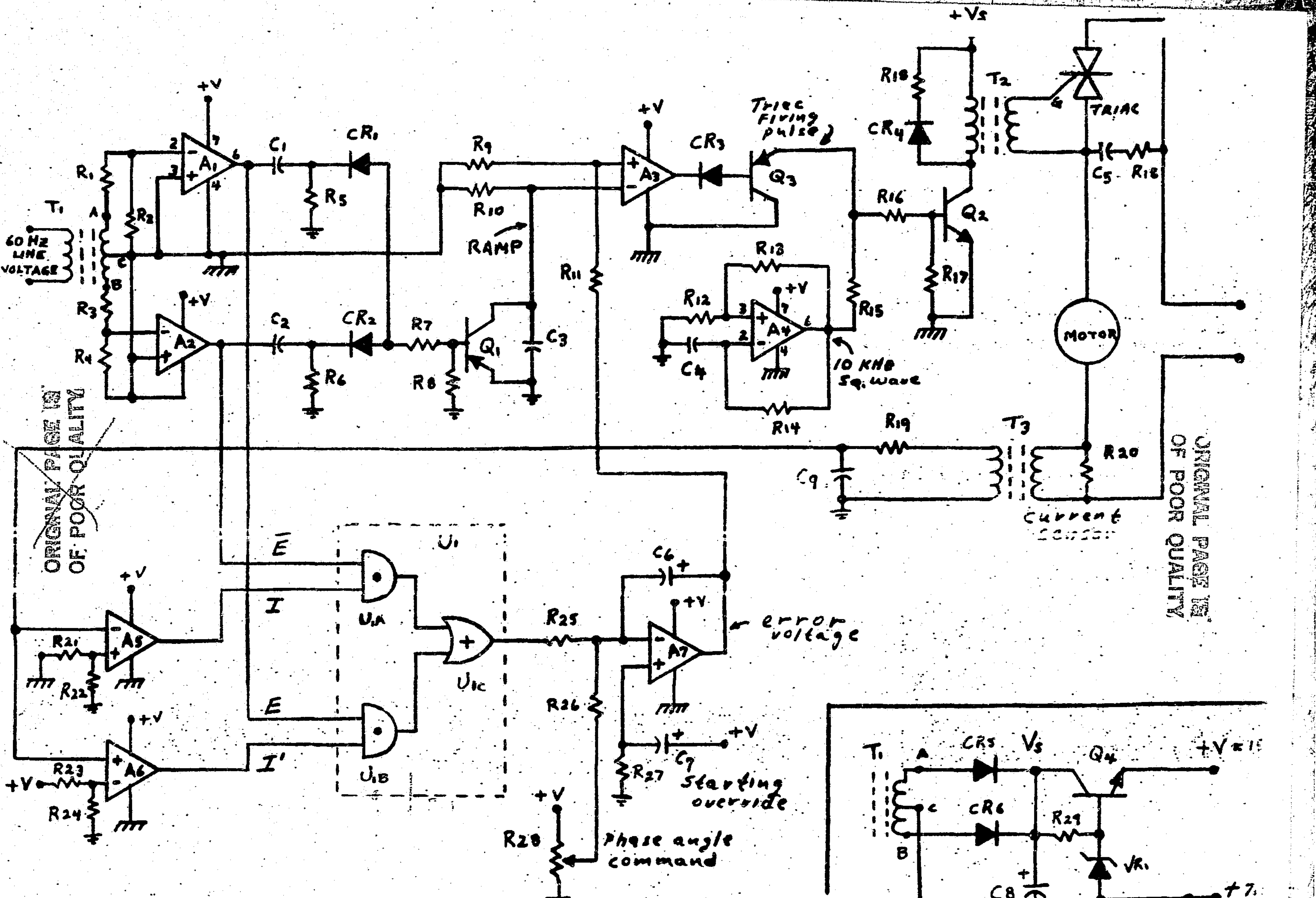
SHEET NO. ______ OF ______

JOB NO. ______

SUBJECT ______

BY J. Monrency DATE 1 May 78

CHKD. BY ______ DATE ______



A1 - A3, A5 - A7 : CA3140T

A4 CA3130

U1 : CD 4019B

Q2, Q4 : 2N2222A

Q3, Q1 : 2N2907A

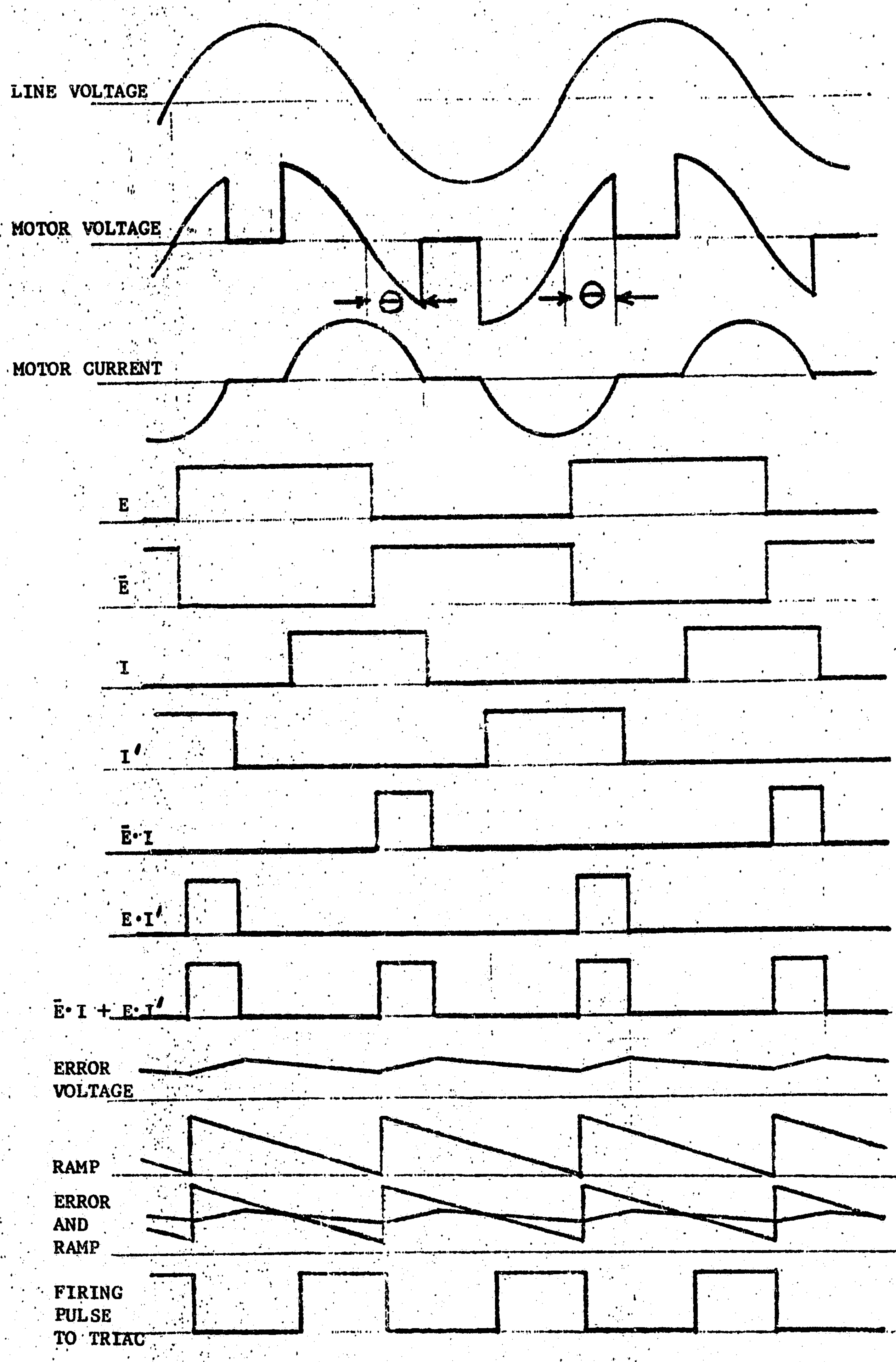
VR1, VR2 : 1N755A

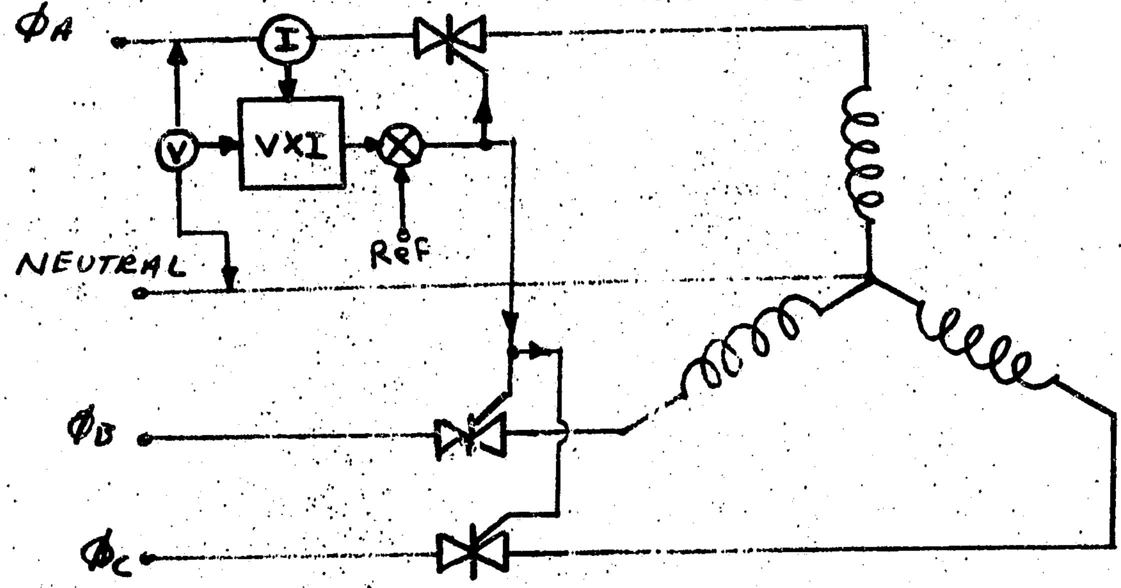
CR1 - CR4 : 1N483 B

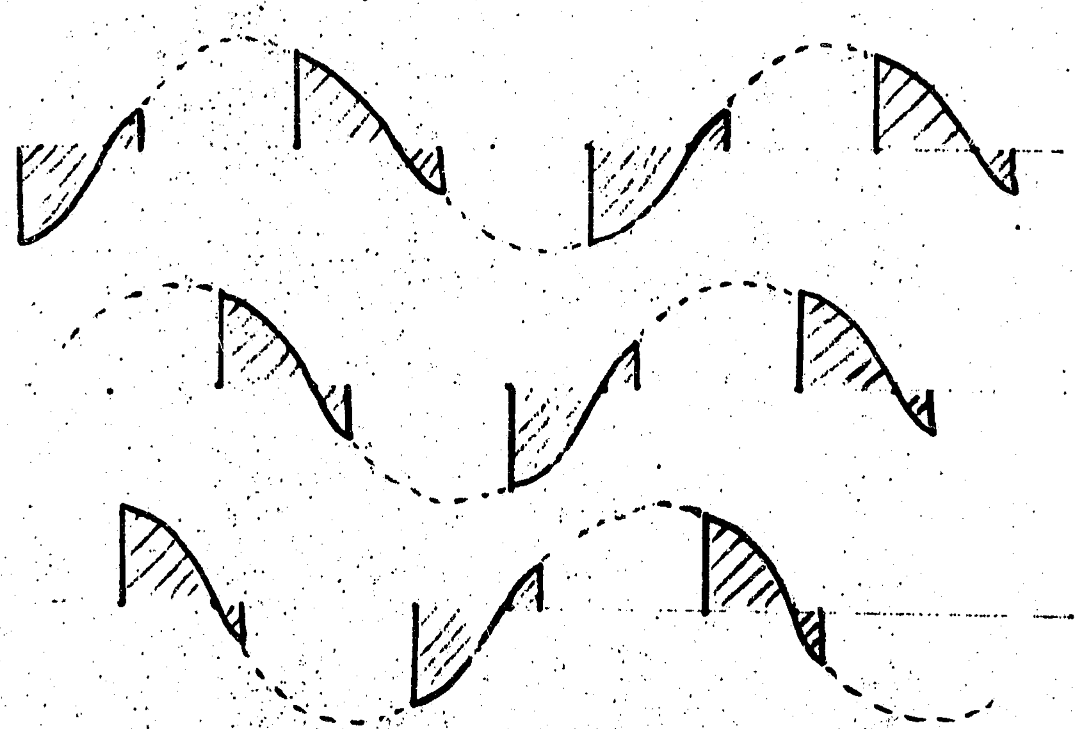
T1 : 115V To 25V

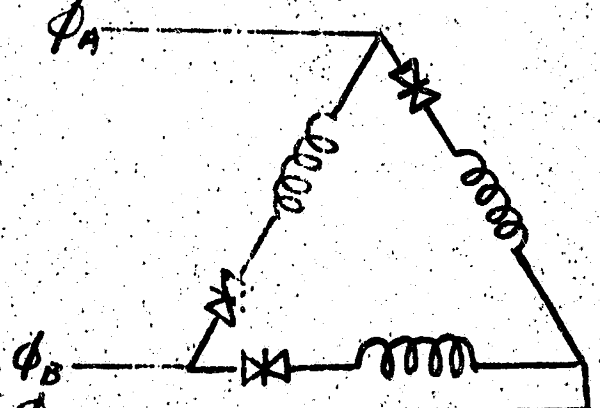
T2 : 4:1

T3 : 1:2


LINE VOLTAGE
MOTOR VOLTAGE
θ
θ
MOTOR CURRENT
E
Ē
I
I'
Ē·I
E·I'
Ē·I + E·I'
ERROR VOLTAGE
RAMP
ERROR AND RAMP
FIRING PULSE TO TRIAC


ϕ_A
I
V
VXI
NEUTRAL
Ref
ϕ_B
ϕ_C




ϕ_A
ϕ_B
ϕ_C

APPENDIX E

DESCRIPTIONS OF END-USER CATEGORIES

Use Category	SIC	Description
Agricultural	01,02,07,08,09	Crops, Livestock, Agric. Services, Forestry and Fishing
Mining	10-14	Metals, Coal, Oil & Gas & Minerals
Construction	15-17	Building Contractors
Mfg. Non-Durable		
Food	20	Meat Packing, Dairy Products Cured and Preserved Products, Grain Mill & Bakery Products, etc.
Textiles	22	Woven and Knit Fabrics, Yarn & Thread, Dyeing and Furnishing, Floor Coverings
Paper	26	Pulp and Paper
Chemicals	28	Chemicals & Gases, Synthetic Resins, Drugs, Detergents, Paints, Fertilizers
Petroleum	29	Gasolines, Oils, Paving & Roofing Materials, etc.
Rubber	30	Rubber and Plastics
Other	21,23,27,31	Tobacco, Apparel, Printing, Leather
Mfg. Durable		
Furn. Lumb.	24,25	Logging, Sawmills, Prefab Building & Mobile Homes, Furniture & Fixtures
Stone	32	Stone, Clay, Glass and Concrete Products
Prim. Metal	33	Blast Furnaces, Rolling and Furnishing, Smelting, Drawing, Extrusion & Foundries
Fab. Metal	34	Cans, Tools, Heating Equip. Structural Metal, Forgings, Stampings, Ordnance, etc.
Non-Elec. Mach.	35	Engines, Farm, Construction & Mining Equip., Metalworking Mach. Special Ind. Equip. Pumps
Elec. Mach.	36	Elect. Transmission, Appliance, Communication Equip., Electronic Components, Electric Motors
Trans. Equip.	37	Motor Vechicles, Aircraft, Ship Building and Railroad Equip.
Other	38,39	Engineering, Laboratory & Scientific Equip.; Jewelry, Toys, etc.
Trans. Comm. Util.		
Trans. Comm.	40,41,42,45,48	Railroads and Bus Terminals, Trans. Warehousing, Airports, Telephone, Offices, Radio & TV Facilities
Pipelines	46	Petroleum Pipelines
Elec. Util.	491	Elect. Power Generation & Transmission
Gas. Util.	492,493	Gas Transmission & Distribution
Water	494,495,496	Water Supply, Sanitary Services and Steam Supply
Irrigation	497	Water Supply for Irrigation
Commercial		
Wholesale	50,51	Principally Distributors
Retail	52-59	Principally Stores
FIRE	60-67	Finance, Insurance & Real Estate
Pub. Ad.	43,91-97	Postal Service, Executive, Legislative Government and National Security (Military) and State Depts'

Use Category	SIC	Description
Services		
Hotels	70	Hotels, Motels, and Tourist Courts
Pers. Serv.	72	Laundry, Beauty and Barber Shops, Funeral, Shop Repair, etc.
Auto	75,76	All Automobile Repair
Recreat.	78-79	Theaters, Bowling, Golf, Commercial (pro) Sports, Amusement Parks, etc.
Medical	80	Hospitals, Nursing Homes, Doctors and Dentists Office, Laboratories, etc.
Educational	82	Schools, Colleges and Universities
Other	73,81,83,84,86,89	Advertising, Employment, Data Processing, Social Services, Museums and Galleries, Organizations and Misc. Services
Households	88	Homes and Apartment Buildings

APPENDIX F

Pg	1	2	3																	
REV	A	A	A																	
Pg																				
REV																				

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

DR EH DATE 2/20/81	TRIAC SELECTION SINGLE PHASE MPC MODEL EY1021
APV EH	
Pg 1 of 3	DD-0012

Pg	1	2	3																		
REV	A	A	A																		

Pg																					
REV																					

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

DR EY DATE 2/20/81
APV EY

TRIAC SELECTION
SINGLE PHASE MPC
MODEL EY1021

Pg 1 of 3 | DD- 0012 | A

TRIAC SELECTION - 1φ MPC

HP	FLA	V (MOT)	PD	TRIAC	I_T	V_{DRM}	HS
1	8.3	120	10	2N5573	15	200	A
				T4120B	15	200	A
				SC250B(orB4)	15	200	A1
1	8.3	240	5	2N5574	15	400	A
				T4120D	15	400	A
				SC250D(orD4)	15	400	A1
3	24.9	120	30	T6420B	40	200	B
				SC265B(orB4)	40	200	B
3	12.5	240	15	T6421D	30	400	A
				SC260D(orD4)	25	400	A
5	41.4	120	50	T8411B	60	200	C
5	20.7	240	25	T6421D	30	400	B

NOTES:

1. Refer to IVECO DD-0013 for Heat Sink A
   Refer to IVECO DD-0013 for Heat Sink B
   Refer to IVECO DD-0013 for Heat Sink C
2. Calculations based on:

$$I_{FLA} = \frac{(746)\,HP}{V(MOT)\,(eff \;\&\; pf)}$$

where: $(eff \;\&\; pf) \triangleq 0.75$

3. All triacs are isolated types.

Edward [signature]

SINGLE PHASE MPC
TRIAC SELECTION

P2 OF 3	DD - 0012	REV A

DEFINITIONS

HP	Horsepower
FLA	Full Load Amps (associated with motors)
V(MOT)	Motor Voltage (line)
PD	Power Dissipation in triac element (or SCR) in Watts
I_T	Triac steady-state current maximum.
V_{DRM}	Triac OFF-state maximum voltage.
HS	Heat Sink.

SINGLE PHASE MPC
TRIAC SELECTION

APPENDIX G

NASA PATENT 4,052,648

APPENDIX G

United States Patent [19]

Nola

[11] **4,052,648**

[45] **Oct. 4, 1977**

[54] **POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS**

[75] Inventor: **Frank J. Nola**, Huntsville, Ala.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[21] Appl. No.: **706,425**

[22] Filed: **July 19, 1976**

[51] **Int. Cl.**[2] **H02K 17/04**

[52] **U.S. Cl.** **318/200; 318/227; 318/230**

[58] **Field of Search** .... **318/200, 227, 230, 231, 318/221 R, 216**

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,441,823 4/1969 Schlabach .... 318/221 R

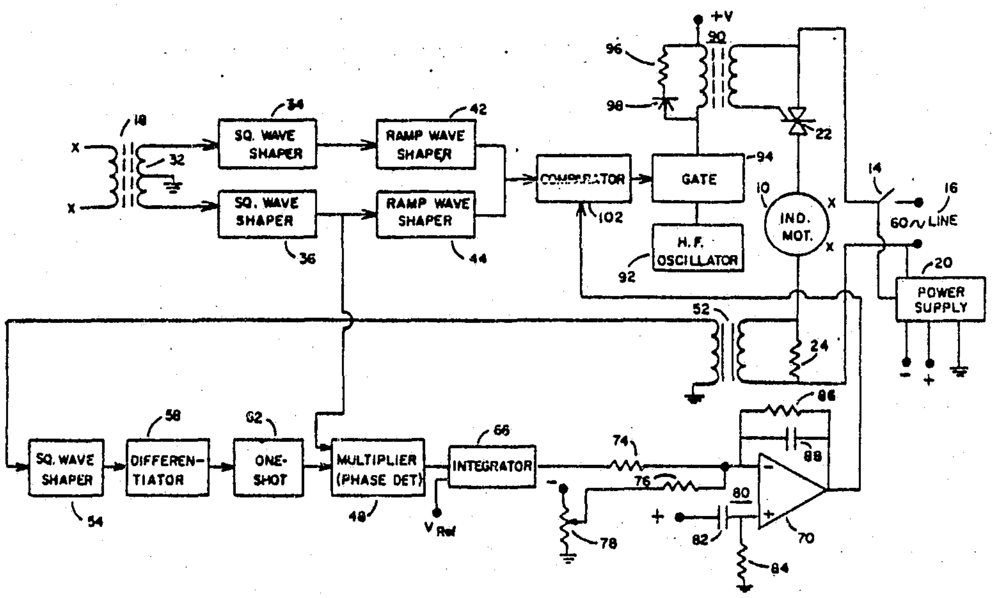
Primary Examiner—Herman J. Hohauser

Attorney, Agent, or Firm—L. D. Wofford, Jr.; George J. Porter; J. R. Manning

[57] **ABSTRACT**

A power factor control system for use with AC induction motors which samples line voltage and current through the motor and decreases power input to the motor proportional to the detected phase displacement between current and voltage to thereby provide less power to the motor, as it is less loaded.

5 Claims, 3 Drawing Figures



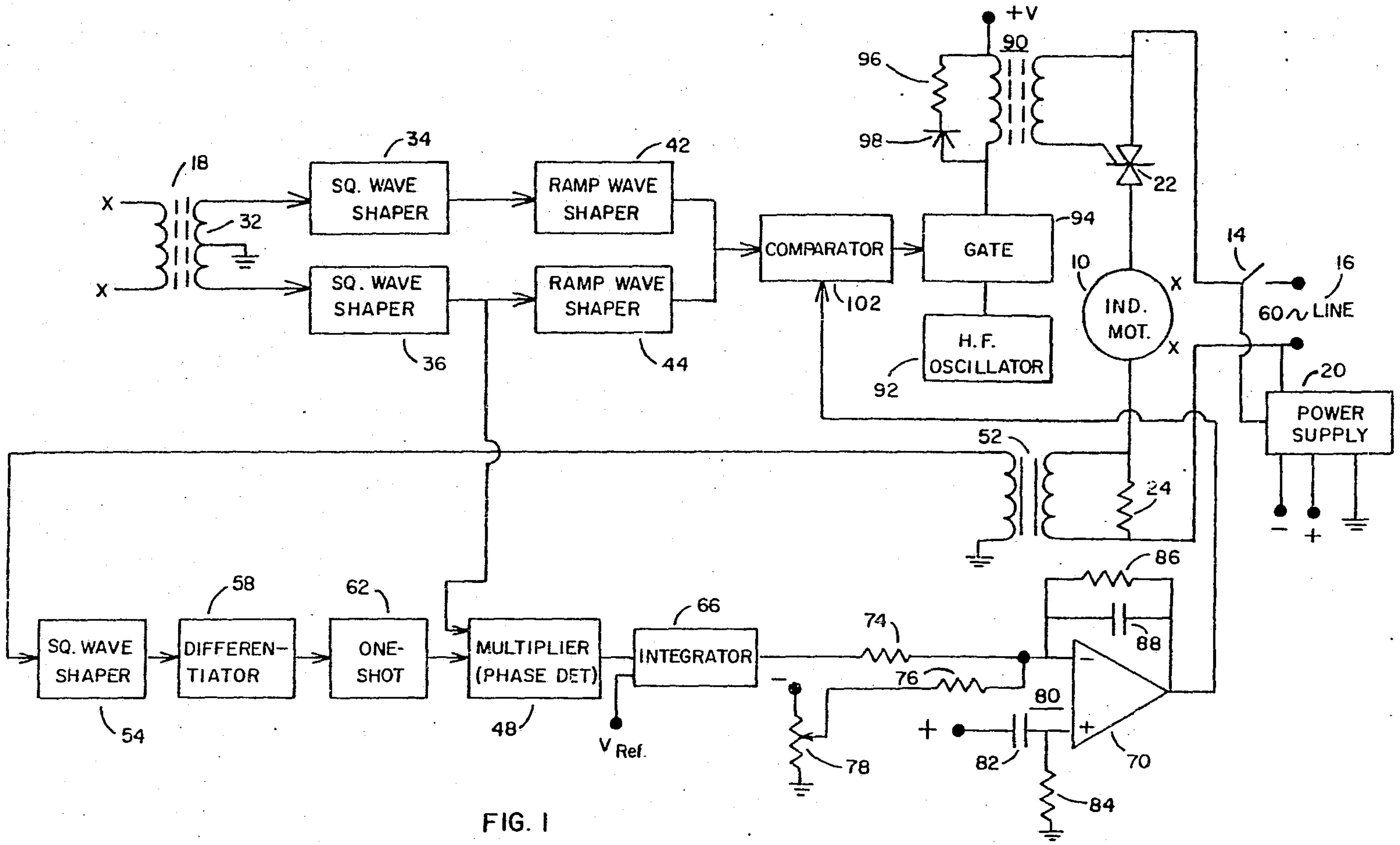

X
X
18
32
SQ. WAVE SHAPER
34
SQ. WAVE SHAPER
36
RAMP WAVE SHAPER
42
RAMP WAVE SHAPER
44
COMPARATOR
102
GATE
94
H.F. OSCILLATOR
92
+V
90
96
98
22
IND. MOT.
10
X
X
14
16
60~ LINE
POWER SUPPLY
20
−
+
52
24
86
88
SQ. WAVE SHAPER
54
DIFFEREN-TIATOR
58
ONE-SHOT
62
MULTIPLIER (PHASE DET)
48
V Ref.
INTEGRATOR
66
74
76
78
80
82
84
70
+

FIG. I

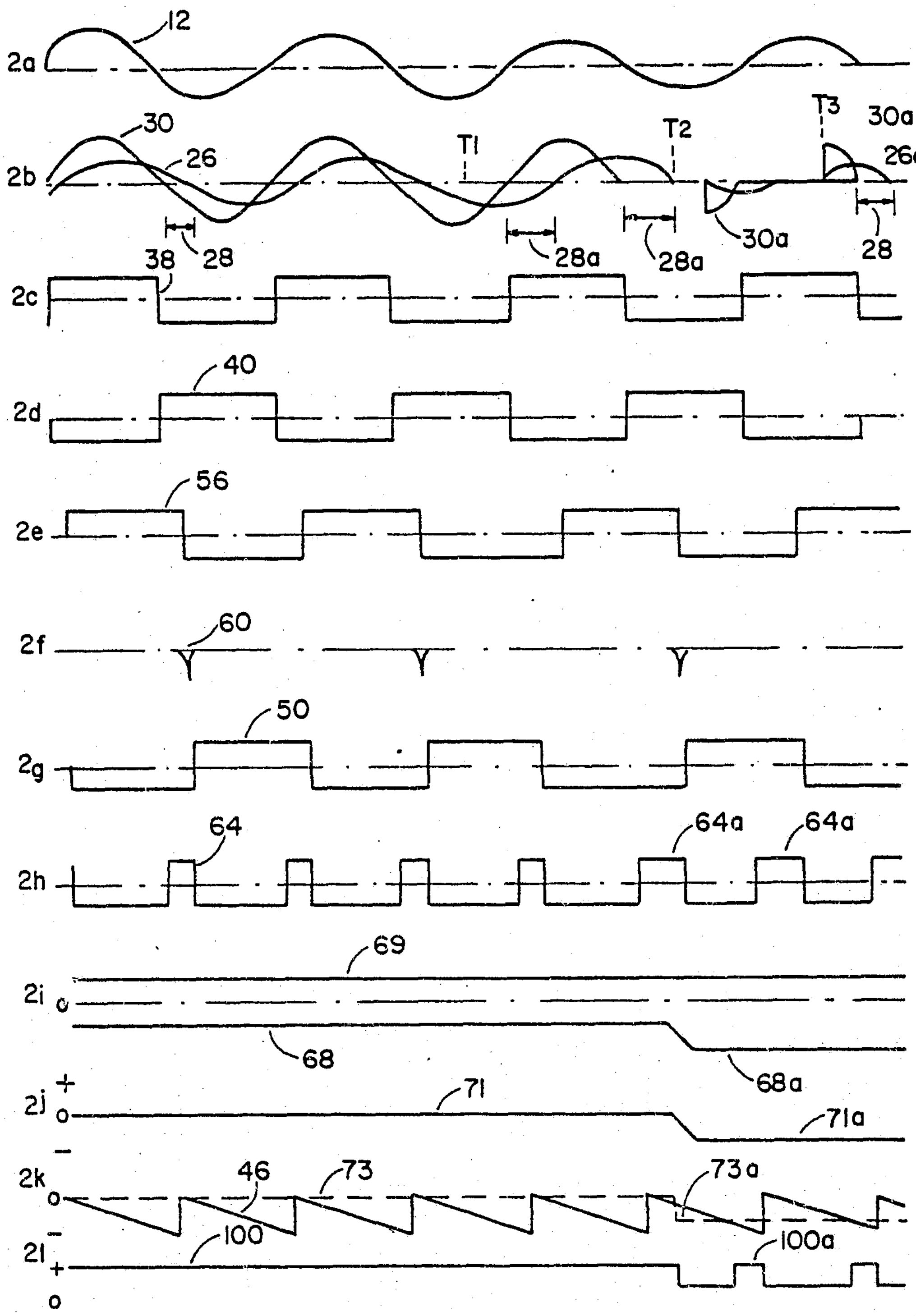

12
2a
30
26
T1
T2
T3
30a
26a
2b
38
28
28a
28a
30a
28
2c
40
2d
56
2e
60
2f
50
2g
64
64a
64a
2h
69
2i
o
68
68a
+
2j
o
71
71a
−
46
73
73a
2k
o
−
100
100a
2l
+
o

FIG. 2

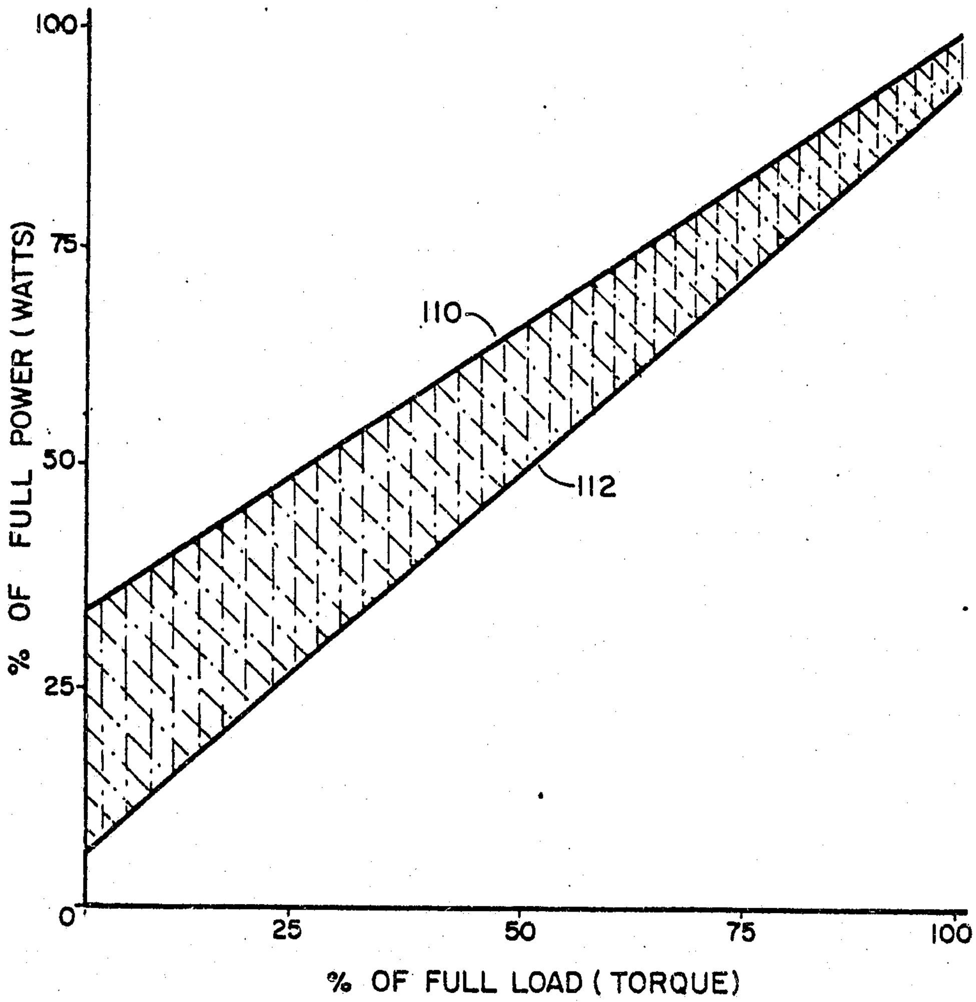

100
75
50
25
0
% OF FULL POWER (WATTS)
110
112
25
50
75
100
% OF FULL LOAD (TORQUE)

FIG. 3

POWER FACTOR CONTROL SYSTEM FOR AC INDUCTION MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to power input controls for motors, and particularly to a control which varies input power to an AC induction motor proportional to loading on the motor.

2. General Description of the Prior Art

The induction motor is perhaps the most rugged, and is certainly one of the most commonly used motors. It runs at an essentially constant speed which, within certain limits, is independent of both load and applied voltage. For efficient operation, the applied voltage should be a function of the load. Heretofore, this has not been practically accomplished. Line voltages are a matter of availability from a local utility. In the case of nominal **115-volt** service, line voltage may be typically in the range of 105 to 125 volts and may not be constant with the service from a particular source and often varying significantly over a 24-hour period. In recognition of this, typically a 115-volt motor would be designed to deliver its rated load plus a safety margin at an under voltage condition of 105 to 110 volts. However, in taking care of the ability of the motor to perform its rated job at under voltage conditions, it becomes wasteful when line voltage is in the 120- to 125-volt range. Further, since this type of motor draws essentially the same current whether loaded or unloaded, motor efficiency goes down when less than a rated load is applied to the motor. Thus, where a user employs a motor over-rated for a job or a variable load is applied to the motor, efficiency suffers and waste of electrical power occurs.

3. Object of the Invention

It is the object of this invention to provide an electrical device which, when placed in circuit with the power input of an AC induction motor, will effect a reduction in power normally provided the motor when operated in either a condition where line voltage is greater than normal and/or motor loading is less than a rated load.

SUMMARY OF THE INVENTION

In accordance with the invention, the voltage applied to an AC induction motor and current through that motor are sampled, the phases of the samples are compared, and a control signal representative of the difference is obtained. This signal is then employed to vary the duty cycle portion of each cycle (portion of each cycle of alternating current) applied to the motor, decreasing the duty cycle proportional to phase difference to thereby regulate phase difference and thus improve the power factor to a more optimum state when there is otherwise present less than an optimum relationship between line voltage and motor load.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an electrical schematic diagram of an embodiment of the invention.

FIGS. *2a–2l* are waveforms illustrating aspects of operation of the invention.

FIG. **3** is a plot illustrating power drawn by a motor for different states of loading and with and without the control system of this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

An AC induction motor **10** is powered by an alternating current voltage **12** (FIG. *2a*) through switch **14** and connectible at terminals **16.** The switched AC power is also applied to transformer **18** and circuit bias power supply **20.** Triac **22** is connected in series with motor **10** and is triggered for controlled portions of each half cycle of power input. A small value resistor **24** of 0.010 to 0.020 ohms is connected in series with motor **10** and serves to develop a signal **26** (FIG. *2b*) which is proportional to the current flow through the motor. FIG. *2b* illustrates an instantaneous state of operation after initial start-up and with an initial optimum input voltage-load relationship, whereby triac **22** is fully on and where, thereafter, loading is substantially decreased. The initial current-voltage phase lag **28** for such optimum state of operation may vary from motor to motor and would be determined for each motor with which this invention is to be employed. In the present example, initially, optimum phase lag **28** is approximately 30°, and potentiometer **78** is adjusted to provide the zero error output signal for the control of the turn on time of triac **22** to maintain the phase angle of this or another selected value. The occurrence of increased current lag **28***a* at time T_1 depicts a sudden decrease in loading of motor **10.** The detection of this is used, as will be further explained, to reduce the average amplitude of input voltage and thereby to effect a commanded, optimum, phase lag.

To further examine the circuitry, transformer **18,** having center tap secondary **32,** provides oppositely phased inputs to square wave shapers **34** and **36,** and the resulting oppositely phased outputs, square wave **38** (from shaper **36**) shown in FIG. *2c* and square wave **40** (from shaper **34**) shown in FIG. *2d,* which are fed to saw tooth or ramp wave shapers **42** and **44,** respectively. The outputs of the wave shapers are combined to provide a ramp wave each half cycle of the alternating current input as shown in waveform **46** of FIG. *2k.* Waveform **38** is also used as a reference signal for the phase of input voltage and is fed to one input of multiplier **48,** functioning as a phase detector, to which is also fed a current reference signal **50** shown in FIG. *2g.* The current reference signal is generated as follows. Current signal **26** (FIG. *2b*) from resistor **24** is fed to isolation transformer **52** and from it to square wave pulse shaper **54,** which provides square wave **56** (FIG. *2e*). This square wave is differentiated in differentiator **58** to provide spike pulses **60** shown in FIG. *2f,* and the negative pulses (derived from the trailing edge of square wave **56**) are used to trigger one-shot **62,** which provides as an output the square waveform **50** shown in FIG. *2g.* This square waveform commences at a time corresponding to the trailing or zero crossing point of current signal **26** (FIG. *2b*) and has a duration (determined by the time constant of one-shot **26**) corresponding to the length of a half cycle of AC input to the motor. Thus, there is generated a square wave current signal which is of the

same duration as a half wave of voltage waveforms 12, 38, and 40, which is shifted in position proportional to the phase shift difference between current and voltage by virtue of the square wave current responsive signal being commenced at the precise end of (zero crossing) a half cycle of the current signal, which ending in time thus varies as a function of current lag.

Multiplier 48 multiplies voltage waveform 38 as shown in FIG. 2c with current waveform 50 shown in FIG. 2g to provide the product output waveform 64 shown in FIG. 2h. This output is integrated and reversed in sense in integrator 66. Except for this reversal, the output of integrator 66 would be maximum for conditions of no current lag and minimum for large current lags. To achieve the opposite sense, a reference voltage v_f is fed to one input of integrator 66 where it is negatively summed with the output of multiplier 48. As a result, the integrated output of integrator 66 is of a value 68, shown in FIGS. 2i and 2j, which varies in magnitude directly with phase angle. In other words, the greater the phase angle the greater the system error which is to be corrected. Output 68 (output 68a after time T_2) of integrator 66, which is proportional to the phase angle, is fed to the negative input of operational amplifier 70. To this same input is also applied an opposite polarity phase angle command voltage 69 (FIG. 2i), being applied through resistor 76 from potentiometer 78. Potentiometer 78 is calibrated to provide an output voltage representative of a desired phase angle to be commanded. Thus, when the system is operating with a commanded phase angle, the output of integrator 66 would be equal and opposite to the command signal from potentiometer 78, a condition shown by FIG. 2j as existing up to time T_2. At this point, by virtue of increased output 64a from multiplier 48 because of increase phase shift 28, the output of integrator 66 increases negatively to a level 68a. Thus, there would initially be a net zero error voltage input 71 (FIG. 2j) to the negative input terminal of amplifier 70. Then, for the indicated phase lag in excess of the commanded phase lag, there would be a finite negative error signal 71a applied to this input, as shown. When this occurs, amplifier 70, which is a high gain amplifier, provides an amplified error signal 73a (FIG. 2k) to comparator 102 to effect such decrease in duty cycle of triac 22 necessary to retain the commanded, optimum, phase angle, in a manner to be described. As shown, this is effected during any interim between times T_2 and T_3.

In order to assure that when motor 10 is first turned on that it will develop maximum torque for a sufficient period to bring the motor up to speed, operation of the control system of this invention is initially delayed. This delay is achieved by delay circuit 80 consisting of capacitor 82 and resistor 84 connected in series between a bias output of power supply 20, which power supply is energized at the same time as motor 10, that is, by the closing of switch 14. Resistor 84 is connected between common ground and the positive input of operational amplifier 70. With a positive potential signal applied to capacitor 82, the initial charging current through resistor 84 is of a value sufficient (determined by the time constant of the combination of resistor 84 and capacitor 82) to override a maximum input applied to the negative terminal for a period of several seconds or longer, depending upon the application. A feedback circuit consisting of resistor 86 and capacitor 88, connected in parallel between the output of amplifier 70 and the negative input of the amplifier, provides the necessary gain and roll off frequency required for system stability.

Triac 22 is gated "on" by a gating signal coupled from the secondary of transformer 90 across an input of triac 22. This gating signal is a high frequency signal generated by oscillator 92 and applied to the primary of transformer 90 through gate or electronic switch 94. Resistor 96 and diode 98 are connected in series across the primary of transformer 90 in order to suppress inductive voltages to a safe level consistent with the semiconductors used. Gate 94 is triggered by pulses 100 (shown in FIG. 2l, and which illustrates "on" time of oscillator 92) from comparator 102 responsive to ramp waveform 46 (FIG. 2k) and control input signal 73 (FIG. 2k). Output pulses 100 from comparator 102 occur during the interval in which control signal 73 exceeds (is more positive than) ramp voltage 46. Thus, in the present example, the output of amplifier 70 initially provides a maximum (in a positive direction) output, and pulses 100 would have a 100 percent duty cycle extending over a full ramp period. This would gate "on" oscillator 92 and thereby triac 22 for the entire portion of input voltage cycle as initially shown for voltage waveform 30 in FIG. 2b. This, it will be assumed, continues for several seconds and until time T_1, at which time the motor loading decreases to near zero. When this occurs, phase lag 28 will increase to some larger value of phase leg 28a, and this will increase, resulting in a shift to the right of current pulse waveform 50 (FIG. 2g), which in turn will provide an increased width output pulse 64 from multiplier 48 (at time T_2). In turn, this will provide an increase in the output of integrator 66 and input to amplifier 70, which will change from a zero level (level 71) to a discrete negative level (level 71a), as shown in FIG. 2j. As a result, amplifier 70 will provide an amplified, less positive, output error signal 73a commencing at time T_2, as shown in FIG. 2k. When this occurs, comparator 102 provides a reduced width pulse 100a to gate 94, and it triggers "on" triac 22 for like decreased width periods to produce a change in input voltage, changing (at time T_3) from that shown by waveform 30 to that shown by waveform 30a.

Thus, motor input voltage waveform 30 goes through a transition during the period of T_1 to T_3, having an initial phase lag 28 to an increased phase lag 28a and then back to the commanded phase lag 28, shifting from full width cycles 30 to extremely short width duration input cycles 30a. The shift in input voltage has been that necessary to re-establish the commanded currentvoltage phase lag, power factor, to thus maintain an optimum power input to motor 10. Had this not been done, the phase angle would have increased substantially, and thus the power factor would have decreased substantially, resulting in a significant waste of power.

FIG. 3 plots the percent of full power applied to motor 10 versus percent of full load, or torque, and line 112 illustrates a case where the control system of this invention is employed. Line 110 illustrates a case where it is not. The hatched difference between the lines is indicative of the power saved by employment of the invention.

While the invention illustrated herein is shown as being usable with a single phase device, it may be connected in circuit with each phase of a multi-stage induction motor. Thus, in the case of a Wye-connected three phase motor, three of the control systems illustrated in FIG. 1 will be employed, one being connected in each of the three phases with each referenced to ground (the

APPENDIX F

ENCLOSURE CONFIGURATIONS
NEMA 1
NEMA 3R

Also add to Table of Contents

NOTES:

1. Enclosure is Wiegman P/N SC463NK
   Cover (outside heatsink) P/N SCF46 "cover A"
   Cover (inside heatsink) P/N SCF46 "cover B"
2. Pgs 1 thru 9 identified as SK081480-1 thru SK081480-8

ORIGINAL PAGE IS
OF POOR QUALITY

Pg	Cover	1	2	3	4	5	6	7	8	9										
REV	A	A	A	A	A	A	A	A	A	A										
Pg																				
REV																				

DR	DATE
EH	8/14/80
APV	
[illegible]	8/14/80

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

ENCLOSURE CONFIG
NEMA 1
SINGLE PHASE MOD EY1021 MAC

DD- 0014 A

EY1021

MOTOR POWER CONTROLLER

ENCLOSURE CONFIGURATION

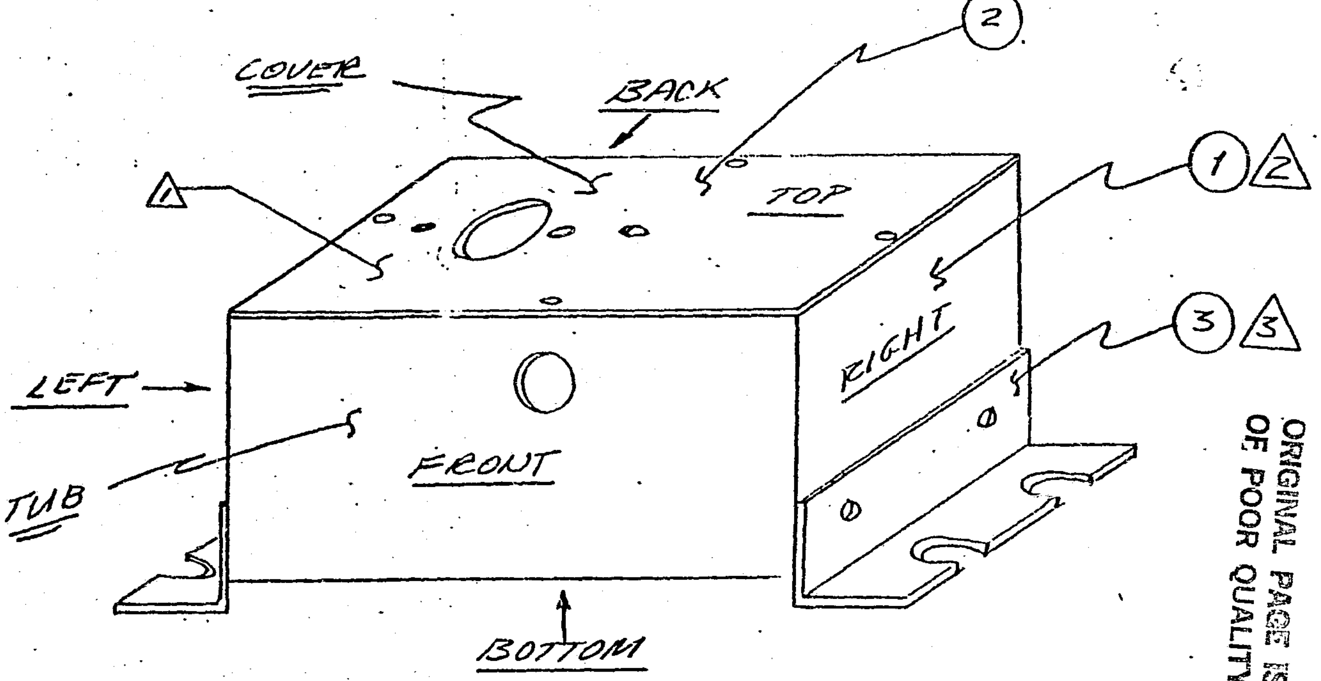
DRAWING PACKAGE

SKETCH No	TITLE	ENCLOSURE CONFIGURATION A	B
SK081480-1	ENCLOSURE "A"	X	—
SK081480-2	ENCLOSURE "B"	—	X
SK081480-3	FRONT VIEW	X	X
SK081480-4	BACK VIEW	X	X
SK081480-5	TOP VIEW COVER A	X	—
SK081480-6	TOP VIEW COVER B	—	X
SK081480-7	BOTTOM VIEW	X	X
SK081480-8	LEFT/RIGHT VIEW	X	X

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

DR: E. [signature] Jr.
8/14/80

ITEM	P/N
1	SC463NK
2	SCF46
3	BKT 1



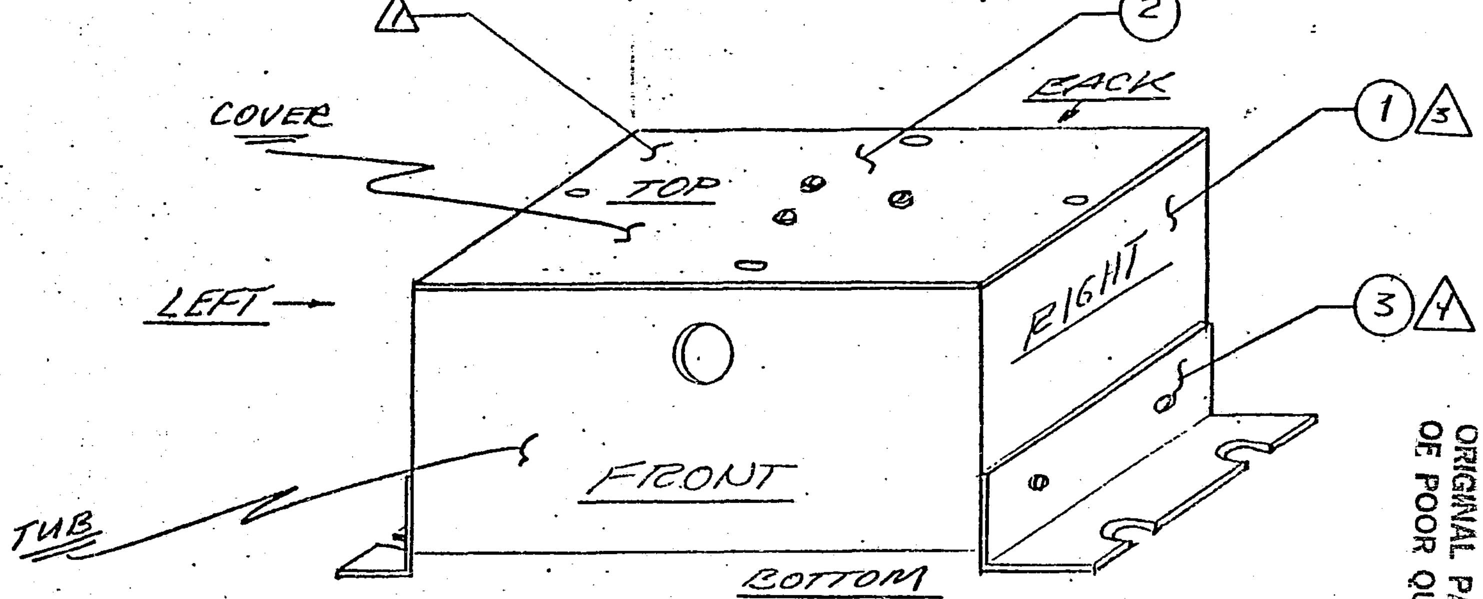
NOTES:

1. TOP also refered to as COVER (FLUSH)
2. Special Wiegmann Pull Box 6"x4"x3" DRILLED
3. See SK081480-8 "BRACKET"
4. TUB same for Enclosure "A" or "B".

EY1021
ENCLOSURE "A"
(3HP-UP)

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK 081480-1



ITEM	P/N
1	SC463NK
2	SCF46
3	BKT 1

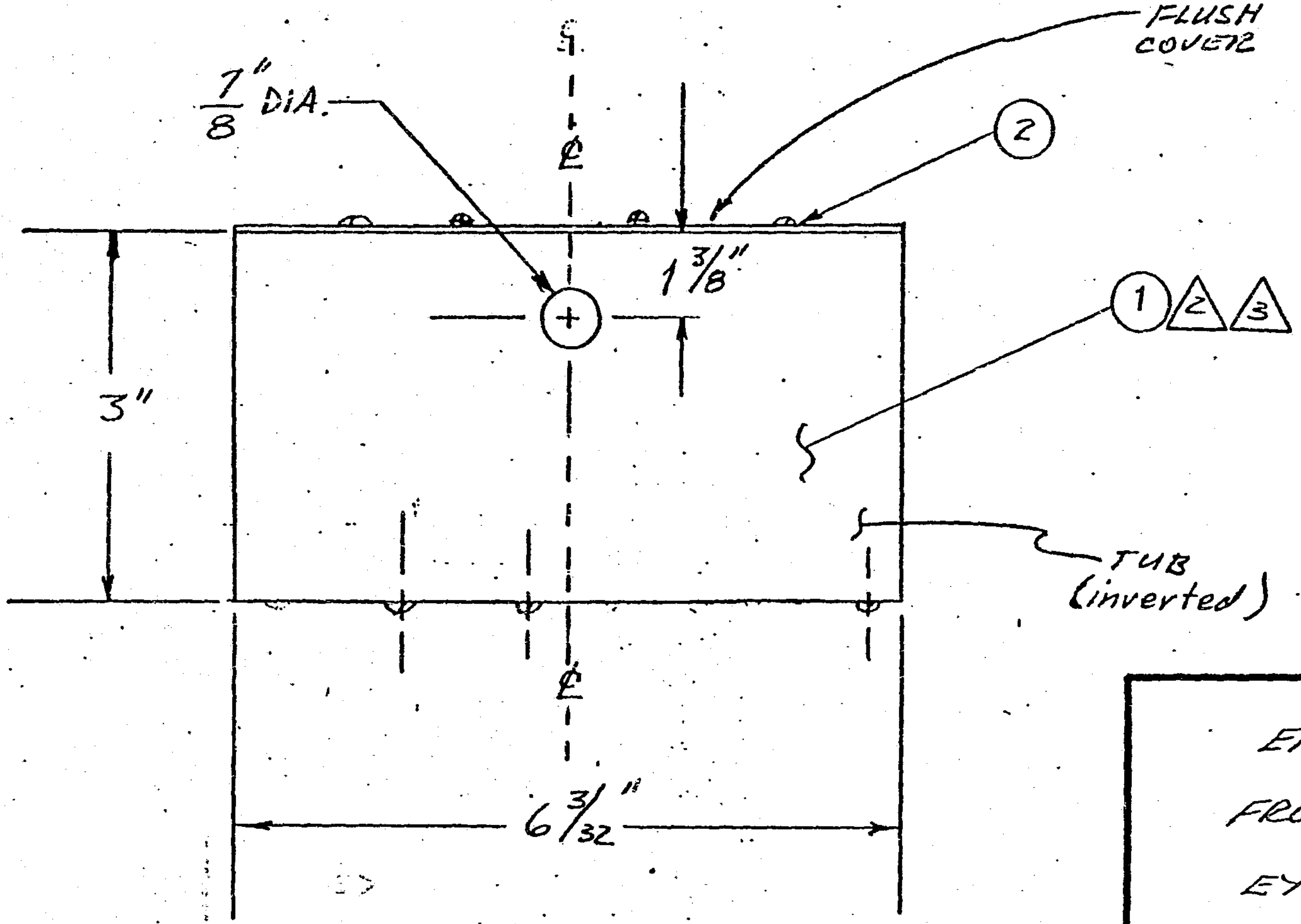
NOTES:

1. TOP also refered to as COVER (FLUSH)
2. NOT TO SCALE
3. Special IVECO/Wiegmann Pull Box 6" x 4" x 3" Drilled.
4. See SK081480-8 "BRACKET"
5. TUB same for Enclosure "A" or "B"

EY1021
ENCLOSURE "B"
3HP-UP

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK081480-2



ITEM	P/N
1	SC463NK
2	SCF 46

1. NOT TO SCALE
2. Special IVECO/Wiegmann Pull Box 6"x4"x3" DRILLED
3. Tub used on either Enclosure "A" or "B"

ENCLOSURE

FRONT VIEW

EY 1021

IVECO
IMPROVEMENT VIA ELECTRONICS
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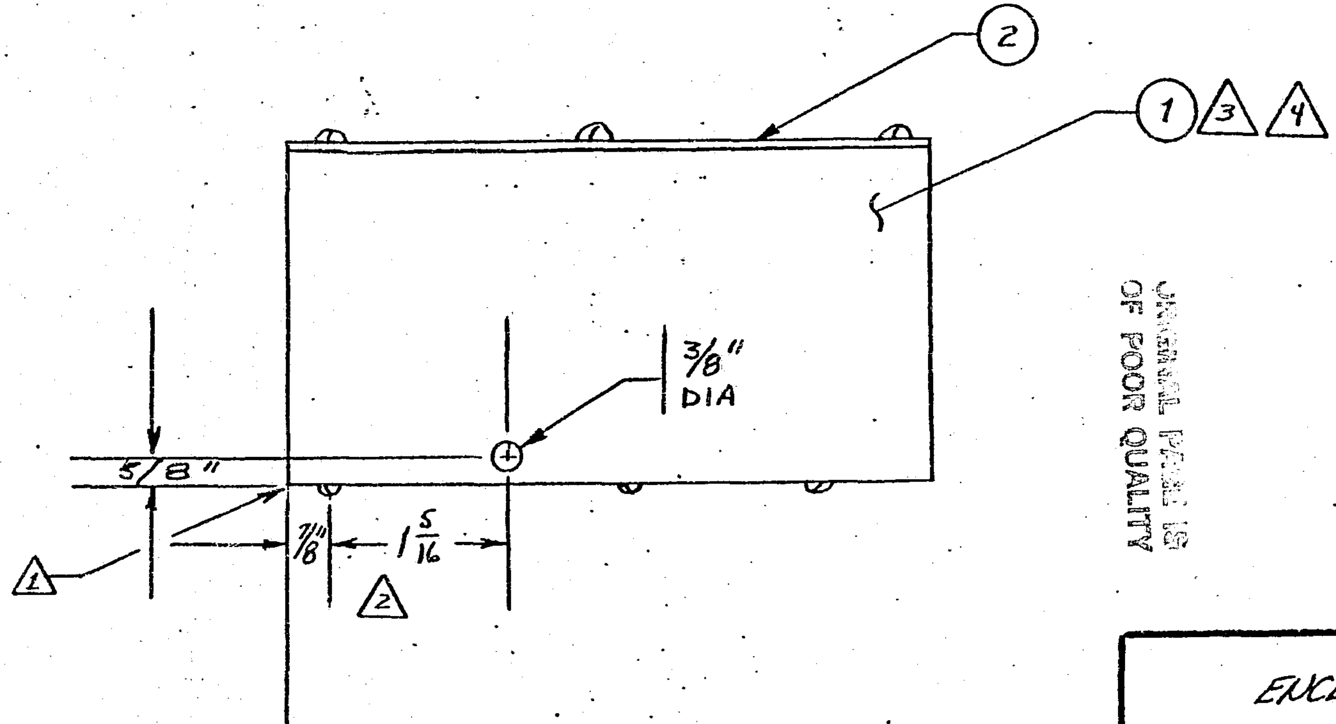
Huntington Beach, CA 92647

SK 081480 - 3



ITEM	P/N
1	SC463NK
2	SCF46

NOTES

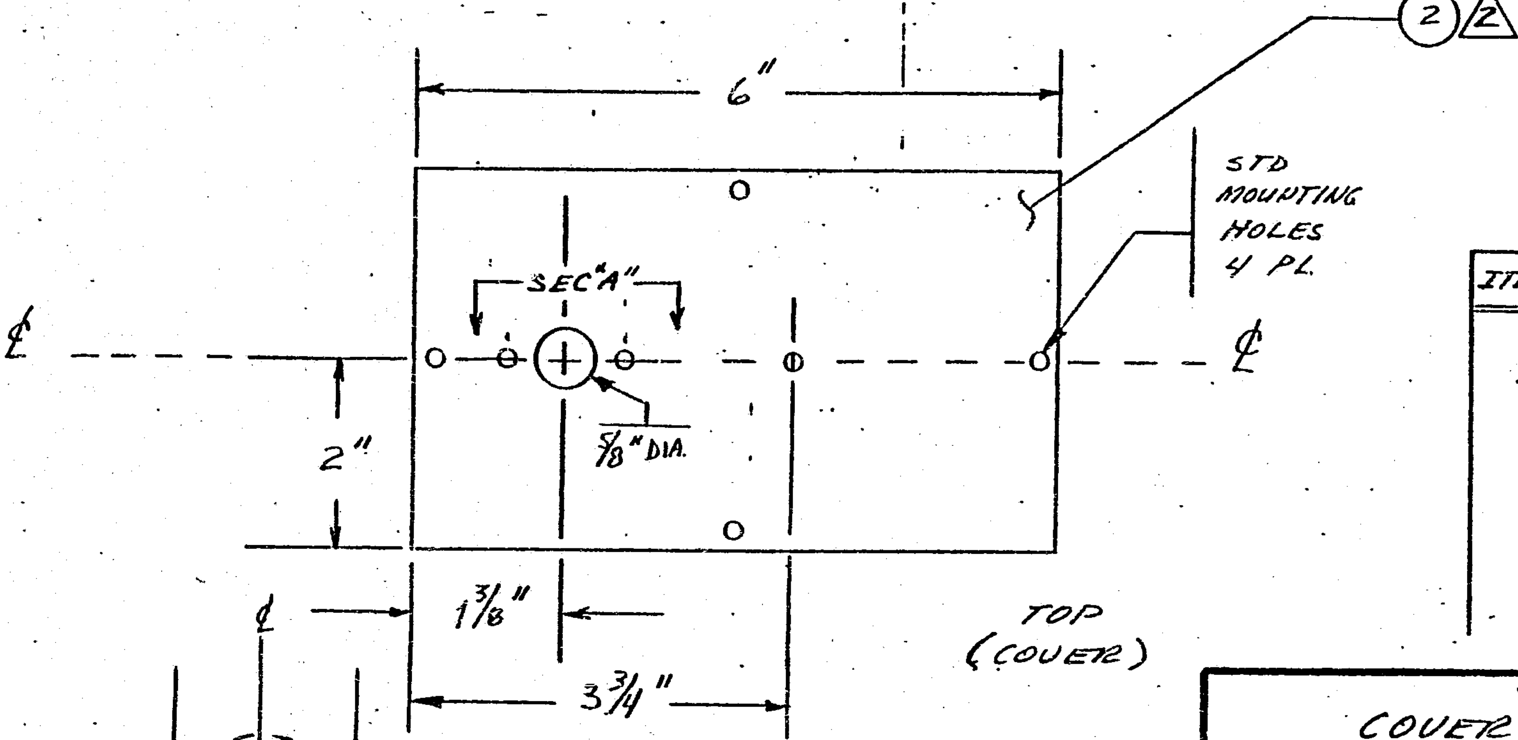
1. Datum is lower left corner.
2. The 1 5/16" DIM must be held with respect to hole in bottom (7/8" Ref) to 0.010."
3. Special IVECO Wiegmann Pull Box 6"x4"x3" DRILLED
4. TUB used on either Enclosure "A" or "B"

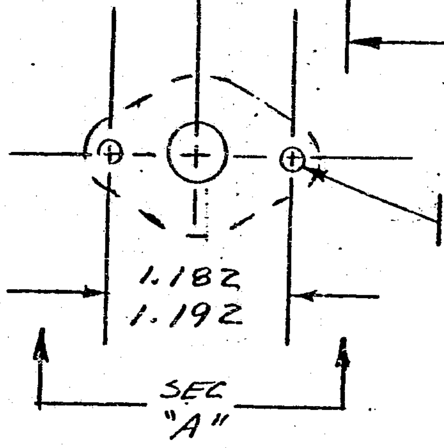
ENCLOSURE
BACK VIEW
EY1021

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK 081480-4

COVER "A"





NOTES:
1. Not To Scale
2. Used on Enclosure "A" Config only.

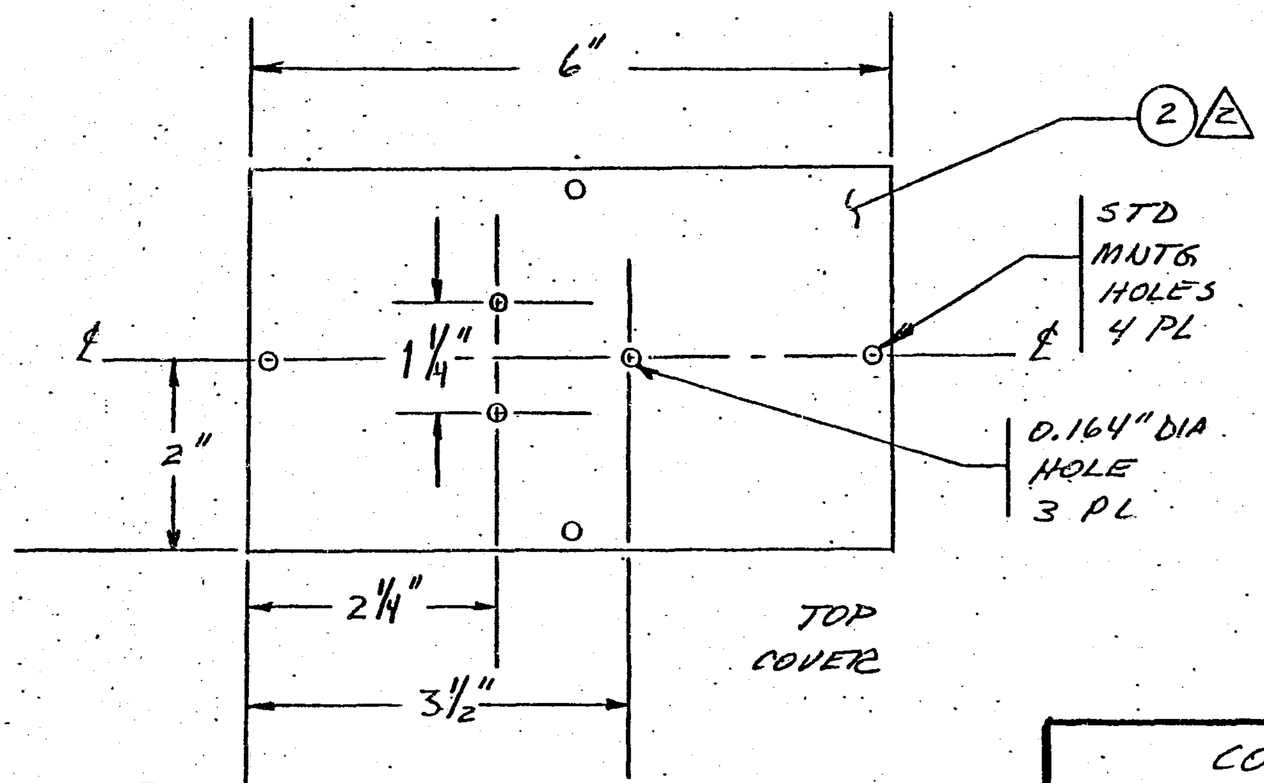
ITEM	P/N
2	SCF 46

COVER "A"
TOP VIEW
(W/ HS)
FLUSH COVER
EY1021

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK 081480-5

COVER "B"



ITEM	P/N
2	SCF46

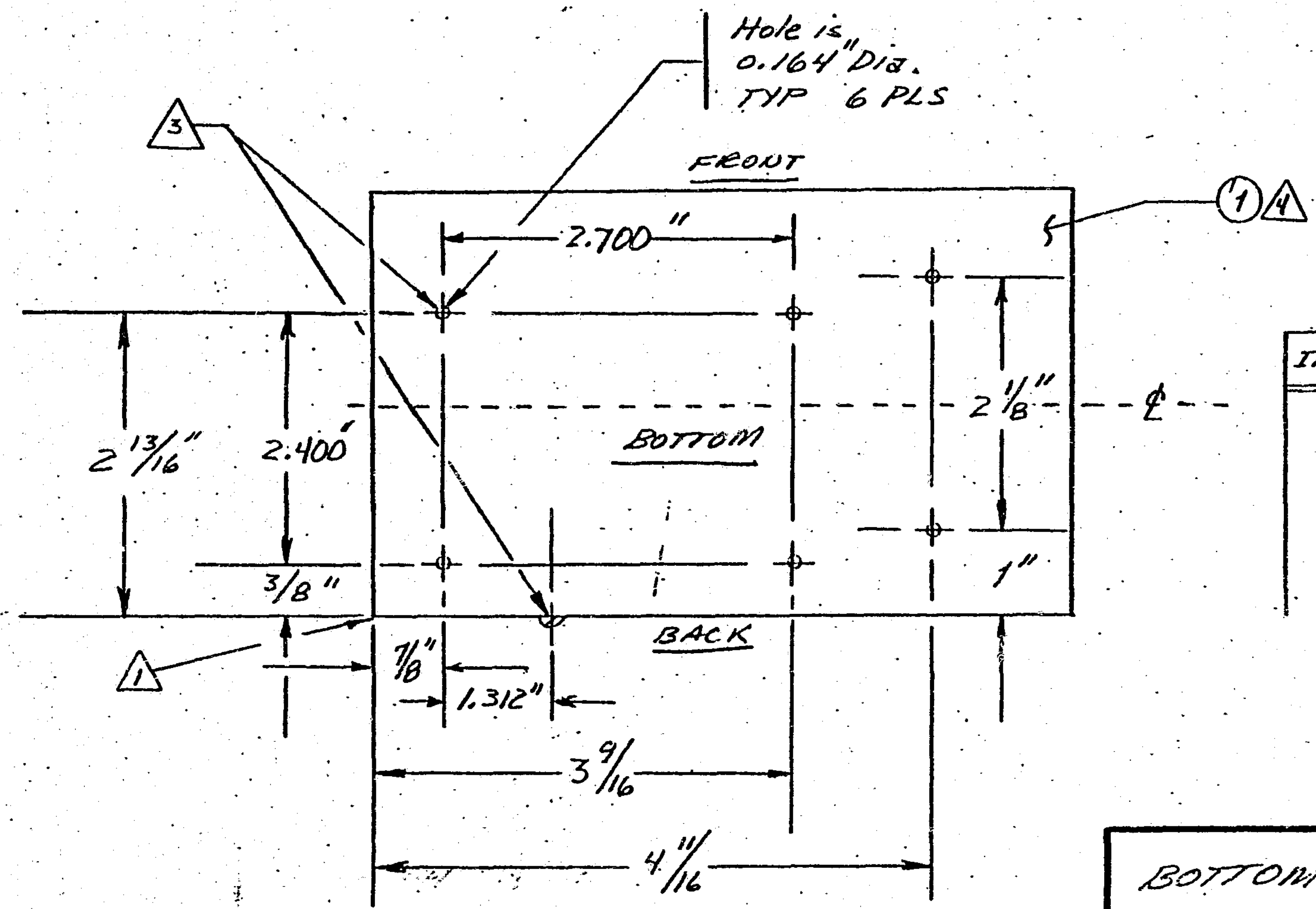
⚠1 NO SCALE
⚠2 Used on Enclosure "B" Config. only.

COVER "B"
TOP VIEW
(W/O HS)

FLUSH COVER
EY1021

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK 081480-6



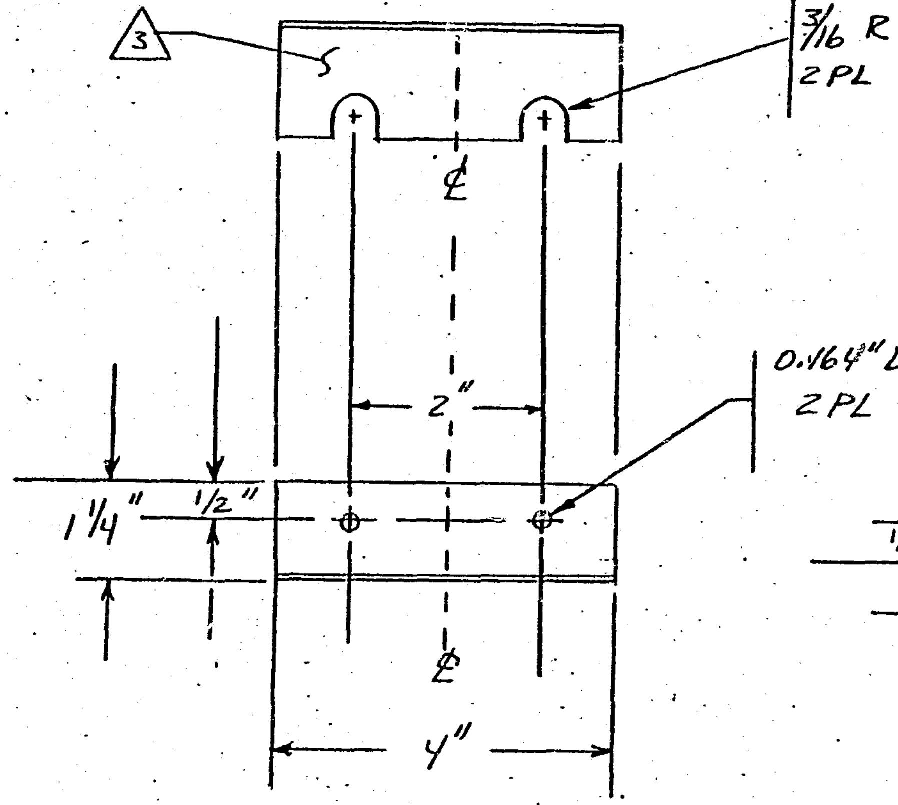
ITEM	P/N
1	SC 463 NK

NOTES:
1. Lower left corner is datum.
2. Ref for all dims are outside edges.
3. Hold relationship of these holes ± 0.010"
4. Special IVECO/Wiegmann Pull Box 6" x 4" x 3" Drilled.

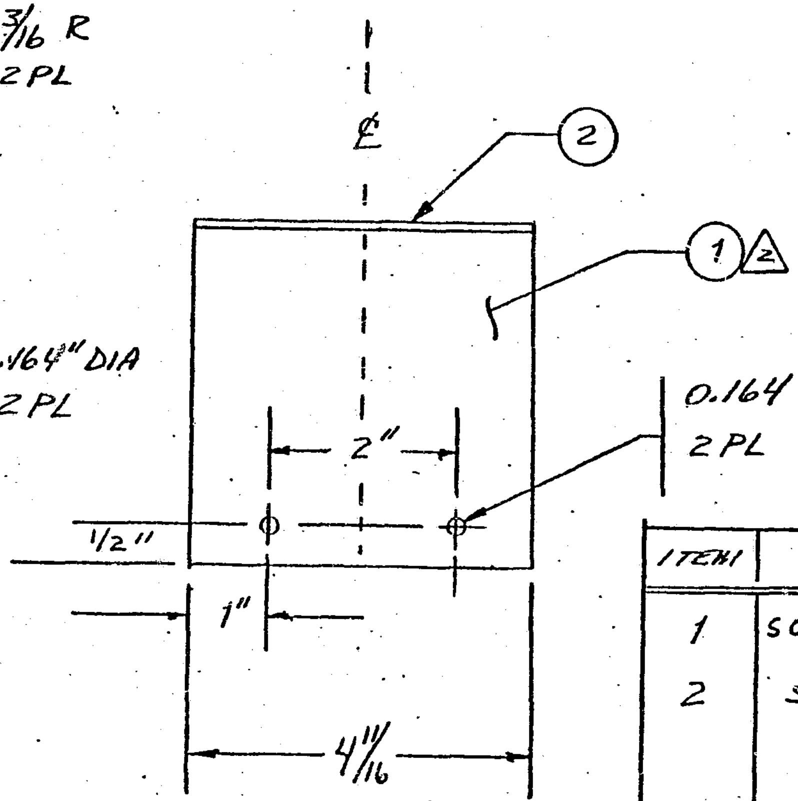
BOTTOM VIEW
EY1021 ENCLOSURE

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK 081480-7



BRACKET
2 REQ'D



LEFT/RIGHT
ENCLOSURE

ITEM	P/N
1	SC463NK
2	SCF46

NOTES:

1. NOT TO SCALE
2. Special IVECO/Wiegmann Pull Box, 6" x 4" x 3" Drilled.
3. 12 or 14 gauge steel, std. grey paint.

LEFT/RIGHT ENCLOSURE & BRACKET

IVECO
IMPROVEMENT VIA ELECTRONICS
17402 Coronado Lane
Huntington Beach, CA 92647

SK081480-8

Pg	
REV	
Pg	
REV	

IVECO

IMPROVEMENT VIA ELECTRONICS

17402 Coronado Lane

Huntington Beach, CA 92647

DR	DATE	ENCLOSURE CONFIGURATION NEMA 3R
APV		SINGLE PHASE MODEL 1021 MPC
		DD- 0015

APPENDIX H

SURGE CURRENT CURVES

T8410 and T8420 Series

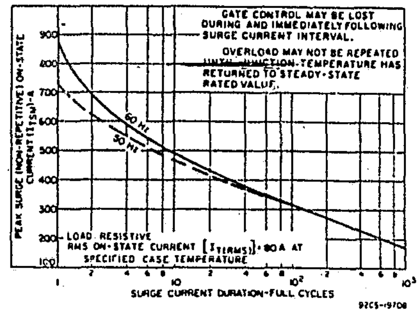


Fig. 4—Peak surge on-state current vs. surge current duration.

T8411 and T8421 Series

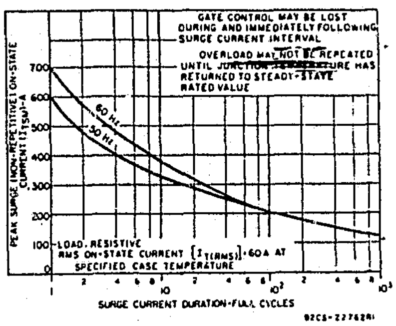
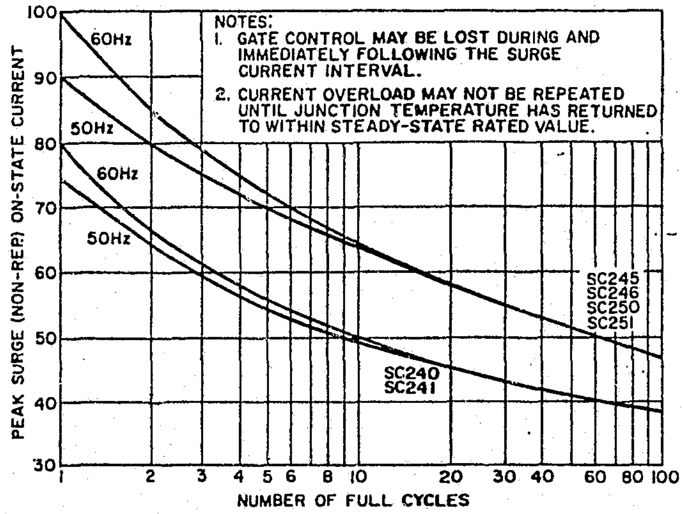
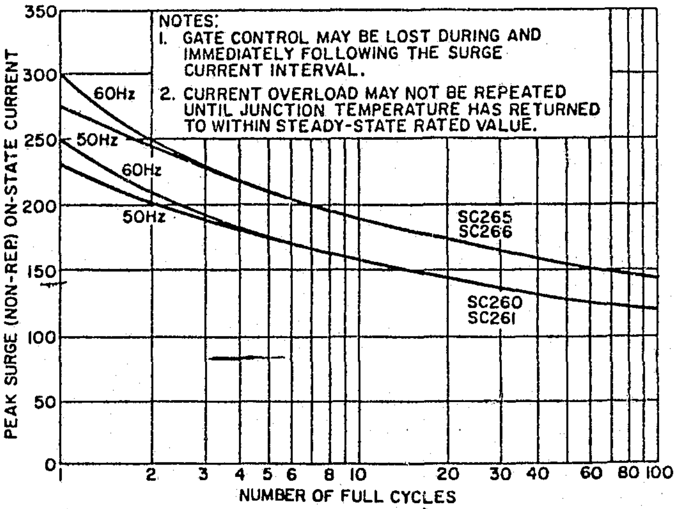


Fig. 4—Peak surge on-state current vs. surge current duration.

STUD/TO-3 FLANGE	PRESS-FIT
SC240, 45, 50, 60, 65	SC241, 46, 51, 61, 66



SC240/SC241, SC245/SC246, SC250/SC251



SC260/SC261, SC265/SC266

T6400, T6410, T6420 Series

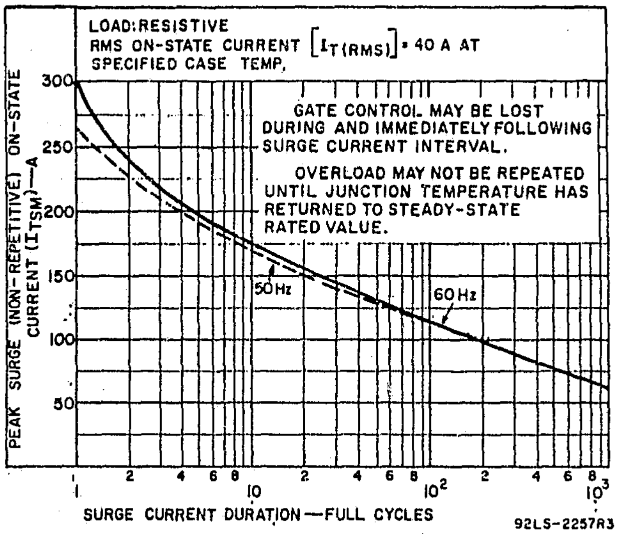


Fig.4—Peak surge on-state current vs. surge current duration.

T6401, T6411, T6421 Series

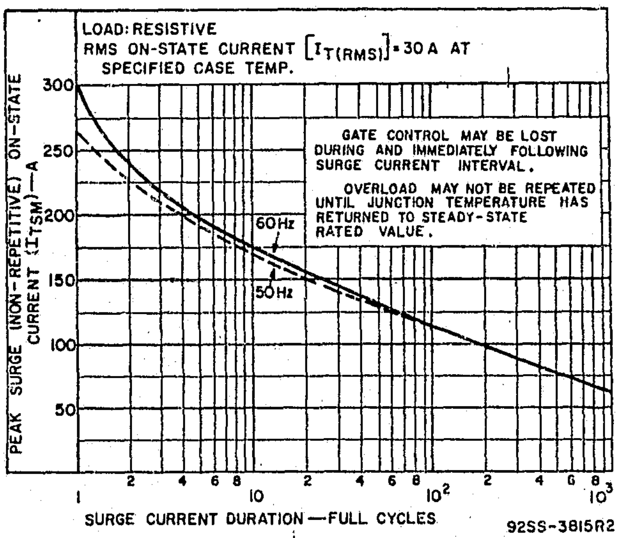


Fig. 4 – Peak surge on-state current vs. surge current duration.

APPENDIX J

THERMAL ANALYSIS, 3Ø CONTROLLERS, 100°F / 80°F

Revised Calculation

Assuming 100°F ambient and 10°C margin on the heat sink

Case To Heat sink Thermal Resistances —

a) 1/4" stud - 11/16 HEX (.83 in²)

.05 — .29 — AHAM
.17 — .56 HAC - & 120 GR.

1/4" stud - 9/16 HEX (.8 in²)

.08 — .48 — AHAM (calc.)
.28 .55 .95 — HAC & 120 GR.
.1 — .15 — RCA (NEW DATA)
.6 — RCA OLD DATA
.4 — GE (REF Telecon)

∴ Assume .5 °C/watt for all 1/4 - 9/16 HEX Devices (Rc-hs, °C/W)

b) 1/2-20 stud & 11/16 HEX

.05 — .15 RCA
.07 — .22 AHAM
.08 — .26 HAC 120 GR.

∴ Assume .2 °C/W

c) TO-3 devices

.06 .12 .20 - HAC

.4 GE

.045 .24 AHAM

Assume .4 °C/W due to the particular construction of the Triacs

I 1 HP, 240 Volts

Using an SC240 (T_J max = 100°C),
T_J = 89°C from a prior calculation
- no heat sink required -

II 5 HP - 480 Volts

Irms / Leg = 7.4 amps
Using T6420N - one diode
per Leg Pd = 5 watts $T_J$max = 110°C
T_{HS} max = T_J - QΣR
= 100°C - 5 (ΣR)
R_{J-C} = 1.0 °C/W R_{C-HS} = .5 °C/W
T_{HS} max = 100°C - 5 (1.0 + .5) = 92.5°C
(102.5°C)

(10)

Assuming an E103 heat sink

6" Long - 3 diodes per heat sink

$P_d = 3(5) = 15 W = 51.15$

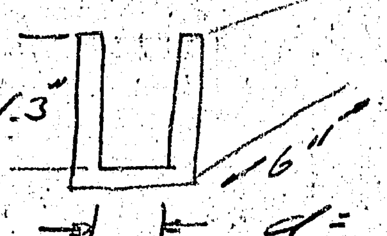
T_{HS}	$\Sigma P_d = 51.15$
150°F	73.44

Looking at the form factor of the E103 HS. again

$P_1 = 1.688(2) + 3.937 = 7.313$

$A_s/in = 21.063$

$P_2 = 21.063 - 7.313 = 13.75$



$d = .4(2); .45(2), 1.35(1)$

$W = 1.3, \quad L = 6.0, \quad D = .4, .45, 1.35$

a) $D = .4 \qquad R_1 = \frac{L}{D} = \frac{6}{.4} = 15$

$R_2 = W/D = 1.3/.4 = 3.25$

$F_W = 1 - .71 = \underline{.28}$

b) $D = .45 \qquad R_1 = \frac{L}{D} = \frac{6}{.45} = 13.33$

$R_2 = \frac{1.3}{} = 2.88 \qquad F_W = 1 - .66 = .38$

(7?)

c) $D = 1.35$

$$R_1 = \frac{L}{D} = \frac{6}{1.35} = 4.44$$

$$R_2 = W/D = \frac{1.3}{1.35} = .96$$

$$F_H = 1 - .34 = .66$$

$$\frac{2(.28) + 2(.38) + .66}{5} = .396 \approx .40$$

$\therefore F_H \doteq .40$

T_{HS} °F	$\Sigma Pd = 51.15$
150	73.1
140	56.1
138	52.7
137	51.15

$\therefore T_{HS} = 137$°F

$\therefore T_J = T_{HS} + \Sigma QR = 137°F + 5(1.0 + .5)(1.8)$
$= 150.5$°F (65.8°C)

III 5 HP 240 volts

I_{RMS}/Leg $= 14.8$ amps

Using one SC260 diode per leg

Pd/diode = 14 watts

$R_{J-C} = 1.55$ °C/watt $R_{C-HS} = .4$ °C/W

T_J max $= 115$°C

T_{HS} max $= T_J - Q\Sigma R = 105 - 14(1.55 + .4) = 77.7$
(171.9°F)

Assuming E103 HS - 6" Long

$\Sigma Pd = 14(3.41)(3) = 143.22$

T_{HS}	$\Sigma Pd = 143.22$
160	91.09
170	109
190	149
185	139
187	143

$\therefore T_{HS} = 187°F$

$T_J = T_{HS} + \Sigma QR = 187 + 14(1.94)(1.8) = 235.89$
(113°C)

If $L = 6.75"$

T_{HS}	ΣPd
170	121.5
180	143.2

$\therefore T_{HS} = 180°F$
STILL excessive

$L = 7.2"$

T_{HS}	ΣPd
170	128
175	139
177	144

$\therefore T_{HS} \cong 176°F$ - STILL Too high

$L = 8"$

T_{HS}	ΣPd
170	140
171	143.25

$\therefore T_{HS} = 171°F$
and is acceptable

$T_J = 171 + 14(1.95)(1.8) = 220.14°F$ (105°C)

Box Size = 6" x 8" x 4"

Consider an E360 HS -

$P_1 = 6.500 + 1.6(2) = 9.7$ in/in

$As/in = 43.2 - 6.5 = \underline{36.7}$ in²/in

$P_2 = 36.7 - 9.7 = 27$

$L = 6"$

Checking As/in - =

$6.500 + (1.6 - .2)(1.1)(2) = \underline{37.3}$ in²

Then $P_2 = 37.3 - 9.7 = 27.6$

	THS	ΣPd = 143.22
L=6.0 }	160	144.86
	159	141.93

∴ THS ≈ 160 °F

$\therefore T_2 = THS + \Sigma QR = 160 + 14(1.95)(1.8)$

$= 209.14$ °F (98.4 °C)

E360 cost - \$6.30 / foot

E 103 cost - \$3.65 / foot

	THS (E360)	ΣPd
L=5.125	165 °F	136.9
	170	149
	167	142
	168	144.6

∴ THS ≈ 168 °F

$T_2 = 168 + 14(1.95)(1.8) = 217.14$ °F (100°

If an SC265 is considered –

$I_{RMS}/Leg = 14.8$ amps

$Pd/diode$ = (one diode per Leg) = 12 W

$R_{J-C} = 1.10$ °C/W $R_{C-HS} = .4$ °C/W

$T_{HS\,max} = T_J - Q \Sigma R = 105\,°C - 12(1.10 + .4)$

$T_{HS}\,max = 87\,°C$ (188.6 °F)

Assuming an E360 section (L = 4")

$\Sigma Pd = 12\,(3)(3.41) = 122.76$ BTU/hr

	T_{HS}	$\Sigma Pd = 122.76$
L = 4"	180	146.4
	175	135.25
	170	124.26
	169	122.09

∴ $T_{HS} \doteq 169$ °F

$T_J = 169 + 12(1.5)(1.8) = 201.4$ °F (94 °C)

T_{HS} $\Sigma Pd = 122.76$

	T_{HS}	$\Sigma Pd = 122.76$
L = 3.5	180	130
	175	120
	177	124.92
	176	122.9

∴ $T_{HS} = 176$ °F

$T_J = 176 + 12(1.5)(1.8) = 208.4$ °F (98 °C)

3.65

∴ Could use three SC265's &

one E360 section 3.5" Long

Assuming E103 section L=6"

	THS	ΣPd=122.76
L=6"	170	109.8
	180	129.37
	175	119.51
	177	123
	176.5	122.4

∴ THS = 176.5°F

& $T_J \cong 98°C$

Cost Summary —

Diode	$ Cost x 3	H.S	$ Cost HS	T_J	$ Σ Cost
SC260	11.01	E103-8	2.43	105°C	13.44
SC260	11.01	E360-5	2.63	103°C	13.64
SC265	12.72	E103-6	1.83	98°C	14.55
SC265	12.72	E360-3.5	1.83	98°C	14.55

Й E103 Section – 5" Long – SC265 (THS°F)

THS	ΣPd = 122.76
180	110.6
188.5	125

∴ Use the 6" Long version

ie SC265 Triacs, E103-6 H.S.

Three Triacs per heatsink —

II (b) Considering the SHP-480 unit condition again —

$P_d = 51.5$

	T_{HS}	ΣP_d	
$L = 3.5''$	150	46.05	
	155	51.64	$\therefore T_{HS} = 155°F$

$T_J = 155 + 5(1.5)(1.8) = 168.5°F\ (75.8°C)$

$\therefore$ Could use T6420N (one per leg) + E103 HS 3.5" long, 3 Triacs per H.S.

If consider no heat sink —

$P_d / \text{Leg} = 5$ watts

$T_{HS} = (198.5°F \max)$

$\Sigma P_d = 5(3)(3.41) = 51.15$ BTU/hr.

$P_1 = 6.0,\ P_2 = 6.0,\ F_N = 1.0$

$T_{°F} = 100 \quad L = 8'' \quad A = 6 \times 8 = \frac{48}{8} = 6$

T_{HS}	ΣP_d	
160	69.68	
150	55.4	
145	49.1	$\therefore T_{HS} \cong 147°F$
146	50.3	
147	51.6	

$h_c = .84$ (REL 12) $h_R = 1.23$

$$Q = K\, m\, A_{cs}\, \theta_o \tanh(mL)$$

$$h = .84 + 1.23 = 2.07$$

$$m = \sqrt{\frac{h \cdot L}{K A_{cs}}} = \sqrt{\frac{(2.07)(6)(144)}{12(27)(.06)(6)}} = 3.916$$

$$\frac{5(3.41)(3)}{2} = (27)(3.916)\left(\frac{(6)(.06)}{144}\right)\theta_o \tanh\left(3.916 \times \frac{4}{12}\right)$$

$$\theta_o = 112\,^\circ F$$

$\therefore T_{HS} = 100 + 112\,^\circ F = 212\,^\circ F$ (excessive)

$\therefore$ a heat sink is required

Assume an E103 heat sink

$\underline{L = 4''}$ Long - $\Sigma Pd = \underline{51.15}$

✓ $\underline{T_{HS}}$ $\underline{\Sigma Pd = 51.15}$

160	64.3
150	51.62

$\therefore T_{HS} = 150\,^\circ F$

$$T_2 = T_{HS} + \Sigma QR = 150 + 5(1.0 + .5)(1.8)$$
$$= 163.5\,^\circ F \; (73\,^\circ C)$$

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IV 10 HP 480 VOLTS

I_{RMS}/Leg = 13.0 amps

Using one T6420N Triac per Leg

P_d = 9.5 watts

$R_{J-C} = 1.0\ ^\circ C/W \qquad R_{C-HS} = .5\ ^\circ C/W$

$T_{HS}\ max = T_J - Q\Sigma R = 100 - 9.5(1.0 + .5)$

$= 85.75\ ^\circ C\ (186.35\ ^\circ F)$

Assuming an E103 section - 6" Long

Three diodes per H.S.

$\Sigma P_d = 9.5(3.41)(3) = 97.185$

	T_{HS}	$\Sigma P_d = 97.185$	
L=6"	170°F	109.84	
	165 °F	100.36	
	164 °F	98.49	$\therefore T_{HS} \cong 163.5\ ^\circ F$
	163 °F	96.63	
	163.5	97.56	

$T_J = T_{HS} + Q\Sigma R = 163.5 + 9.5(1.0 + .5)(1.8)$

$= 189.15\ ^\circ F\ (\underline{\underline{87.30\ ^\circ C}})$

If $L = 4.0''$ (E103) $Pd = 97.185$

T_{HS}	$\Sigma Pd = 97.185$
170	77.57
180	91.38
182	94.21
183	95.68
184	97.05

$\therefore T_J = 184 + 9.5(1.5)(1.8) = 209.7°F\ (98.7°C)$

Use the 6" Length for the sake of uniformity & added reliability

V 10 HP - 240 volt

$I_{rms}/Leg = 25.9$ amps

Assuming 2 diodes per line - Type SC26

$I_{rms}/diode = 13.0$ amps

$\therefore Pd/diode = 10$ watts

$R_{J-C} = 1.10\ °C/watt$ $R_{C-HS} = .4\ °C/w$

$T_{HS}\ max = T_J - Q\Sigma R = 105 - 10(1.10 + .4)$

$= 90°C\ (194°F)$ max.

Assuming again an E360 HS - 6" Long

6 diodes per H.S - $Pd/HS = 60$ watts

$$\Sigma Pd = 60(3.41) = 204.6$$

T_{HS}(°F)	ΣPd
160	144.86
170	174.82
180	206.00
179	202.83

$\therefore T_{HS} = 179°F$

$T_J = 179°F + 10(1.0+.4)(1.8) = 206°F (96.6°C)$

VI 20 HP - 480 volt.

$I_{RMS}/Leg = 25.9$ amps

If one T6420N Triac is used per leg

$Pd = 24$ watts per diode $T_J max = 110°C$

$R_{J-C} = 1.0$ °C/W; $R_{C-HS} = .5$ °C/W

$T_{HS} max = T_{J\,allow} - Q\Sigma R = 100°C - 24(1.5) = 64°C (147.2°F)$

Assume E 360 HS - 6" Long

$$\Sigma Pd = 24(3)(3.41) = 245.52$$

	T_{HS}	$\Sigma Pd = 245.52$
L=6"	130	63.2
	150	116

$\therefore$ 6" is not Long enough

E360-8

	THS	EPd	
L=8"	140	113.6	
	160	184	∴ THS > 147.0°F

E360-10

	THS	EPd	
L=12	140	137	
	150	179	∴ THS ≅ 165°F (Too hi)
	160	223	
	165	246	

E360-12

	THS	EPd = 245.52	
L=12	120	71	
	140	160	∴ THS = 157°F
	150	209	& is still to hi
	160	261	
	155	235	
	157	245	

Considering a AHAM 1700 HEAT SINK

Surface area = 9.124 + 1.0 (24)(2) + .31(2)

= 57.74 in² / in

P_1 = 9.124 + 1.31(2) = 11.744

P_2 = 57.74 − 11.744 = 45.996

ORIGINAL PAGE IS
OF POOR QUALITY

Assume $L = 6''$

$W = 1.0''$ $D = .25''$ $L = 6''$

$R_1 = \frac{L}{D} = \frac{6}{.25} = 24$, $R_2 = \frac{W}{D} = \frac{1}{.25} = 4$

$F_{1-A} = (1 - .8) = .2_{@ L=6''}$

Assume $L = 5''$

$R_1 = \frac{5}{.25} = 20$ $R_2 = 4$ $F_{1-2} = .78$

$F_{1-A} = 1 - .78 = .22$

Assuming one heat sink 5" Long

Three Triacs per heat sink

$\Sigma Pd = 24(3)(3.41) = 245.52$

	T_{HS}	$\Sigma Pd = 245.52$	
	130°F	77.53	
L=5"	140	109.386	
	150	143	
	180	254	∴ $T_{HS} \cong 177°F$
	177	242	which is excessive

Assume $L = 6''$

	T_{HS}	$\Sigma Pd = 245.52$
L=6"	140	125.5
	150	164
	170	247

Assume $L = 8''$

$R_1 = \frac{8}{.25} = 32 \quad R_2 = 4$

$F_{1-A} = 1 - .81 = .19$

	T_{HS}	ΣP_d
L=8	130	112
	140	158
	150	207
	155	232
	160	258

$\therefore T_{HS} \cong 1$

$L = 10'' \quad R_1 = \frac{10}{.25} = 40 \quad R_2 = 4$

$F_{1-A} = 1 - .85 = .15$

T_{HS}	$\Sigma P_d = 245.52$
130	131
140	184
150	241
152	253

$L = 12''$ $\quad R_1 = \frac{12}{.25} \cong 50 \quad R_2 = 4$

$F_{1-A} = .13$

T_{HS}	$\Sigma P_d = 245.52$
130	149.97
140	211.56
145	243.79
147.2	258.25
145.3	245.7

$\therefore T_{HS} = 145.3°F$

$T_J = T_{HS} + Q\Sigma R = 145.3 + 24(1.0 + .5)(1.8)$

$= 210.1°F\ (99°C)$

VII 20HP 240V

$I_{RMS}/Leg = 31.9$ amps

Assuming Two Triacs per Leg -

Type SC265 - $I_{RMS}/_{TRIAC} = 26$ amps

$P_d/_{TRIAC} = 26$ watts $\qquad T_J max = 115°C$

$R_{J-C} = 1.10\ °C/W\ ,\ R_{C-HS} = .4\ °C/W$

$T_{HS}(max) = \underset{(allow)}{T_J} - Q\Sigma R = 105°C - 26(1.1 + .4)$

$= 66.0\ °C\ (\underline{150.8}°F)$

1st assume #1700 HS. $L = 12.0''$

$\Sigma P_d = 26(6)(3.41) = 531.96$

	T_{HS}	ΣP_d	
$L = 12''$	160	345	$\therefore T_{HS} > 180°F$
	180	491	and is unacceptable

Assume Two Triacs per heat sink
Type 1700 - $L = 6''$ $\therefore F_W = .2$

$R_1 = \frac{6}{.25} = 24 \qquad \Sigma P_d = 26(2)(3.41) = 177.3$

THS	$\Sigma Pd = 177.32$

$L = 6''$

140	125
150	164.3
155	184
152	172
153.5	178.34

$\therefore T_{HS} \cong 153.5°F$

$\therefore T_2 = T_{HS} + \Sigma QR = 153.5 + 26(1.4)(1.8)$

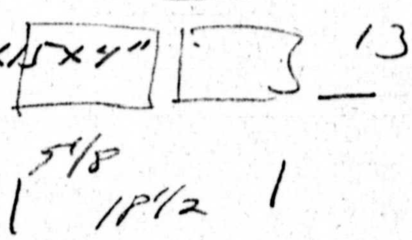
$= 219.02\ °F\ (104°C)$

$\therefore$ Could use three #1700-HS -

Two SC265 diodes per line - each

6" Long

Box size - 18 x 5 x 4"



VI Continued - 20HP - 480 volt

$\Sigma Pd = 245.52$ @ 3 Triacs per H.S.

Considering a 5305 H.S. (R2 23)

$A_s/in = 85.2 - 6.87 = 78.33$

$P_1 = 7.00 + 3.12(2) = 13.24$

$P_2 = 78.33 - 13.24 = 65.09$

$L = 8''$ -

@ $L = 8''$

$R_1 = \frac{L}{D} = \frac{8}{.5} = 16, \quad R_2 = \frac{W}{D} = \frac{2''}{.5} = 4$

$F_{1-A} = 1 - .75 = .25$ THS max = 147.2

	THS	ΣPd = 245.52	
L = 8"	130	155	
#5305	140	219	
	145	~~252~~ 289	∴ THS ≅ 144°F
	143	239	
	144	246	
	143.5	242	

$T_J = 144°F + 24(1.0+.5)(1.8)$
$= 208.8°F \ (98.2°C)$

∴ Use the 5305 HS - 8" Long
Three Triacs per H.S -

VII Continued - <u>20 HP 240V</u>

Pd/Triac = 26 watts

Two Triacs per Leg - SC265

THS max = 150.8°F

Assume all Triacs one one H.S.

$\Sigma Pd = 26(6)(3.41) = 531.96$

Assume L = 15" Type 5305 H.S.

$R_1 = \frac{L}{D} = \frac{15}{.5} = 30 \quad R_2 = 4$

$F_{1-A} = 1 - .82 = .18$

	T_{HS}	ΣPd = 531.96	
L=15"	130	248	
5305	140	350	
	150	458	
	160	571	
	155	514	∴ T_{HS} = 156.5°F
	155.5	520	
	156	525	
	157	537	
	156.5	531.55	

Assume L=16"

	T_{HS}	ΣPd	
L=17			
5305	145	448	
	150	509	∴ T_{HS} = 152°F
	152	533.8	
	151.	521.4	

$$T_J = T_{HS} + \Sigma QR = 152 + 26(1.1 + .4)(1.8)$$

$$= \underline{\underline{222.2°F}} \ (105.7°C)$$ (see pg 116)

VIII 30HP - 480 Volt

I_{RMS} / Leg = 38.9 amps.

Assume Two Triacs per Leg.

I_{RMS} / Triac = 19.5 amps   T6400N

T 6420 N dissipates 16 watts
at 19.5 I_{RMS}

$T_J\ max = 115°C$

$T_{HT}\ max = T_{J_{allow}} - Q \Sigma R = 100°C - 16(1.0 + .5)$

$= 76°C\ (168.8°F)$

If all the Triacs are on one heat sink - $\Sigma Pd = 16(6) = 96$ watts
~~which is a bit high for one H.S.~~
~~Therefore assume 3 Triacs per heat sink - $\Sigma Pd = 16(3)(3.41) = 163$~~

$\Sigma Pd = 96(3.41) = 327.36$

Assume 5305 H.S. - 8" Long

$R_1 = \frac{L}{b} = \frac{8}{.5} = 16, \quad R_2 = 4$

$\therefore F_{1-A} = 1 - .75 = .25$

	T_{HS}	$\Sigma Pd = 327.36$
L = 8"	130	155.79
5305	140	219
	150	287
	160	358
	157	336
	156	329
	155.8	327.9

$\therefore T_{HS} = 155.8°F$

$T_J = T_{HS} + \Sigma QR = 155.8 + 16(1.0 + .5)(1.8) = 199°F\ (92.7$

If $L = 7''$ Type 5305

$R_1 = \frac{7}{.5} = 14$, $R_2 = 4$

$F_{1-x} = 1 - .74 = .26$

	T_{HS}	$\Sigma P_d = 327.36$
	155°F	290.37
$L = 7''$ 5305	160	322.77
	162	335
	161	329
	160.8	328
	160.7	327

$\therefore T_{HS} = 160.7°F$

$T_J = T_{HS} + Q\Sigma R = 160.7 + 16(1.0 + .5)(1.8)$

$= 203.9°F \; (95.5°C)$

IX 30 HP – 240 Volt

$I_{rms}/\text{Leg} = 77.8$ amps

Assuming Two Triac per Leg Type T8421D (Rated at 60 amps each)

$I_{rms}/\text{Triac} = 38.9$ amps

$P_d/\text{Triac} = 42$ watts $T_{J\,max} = 110°C$

$T_{HS\,max} = T_{J\,allow} - Q\Sigma R = 100 - 42(.4 + .2)$

where $R_{J-C} = .4°C/W$ $R_{C-HS} = .2°C/W$

$T_{HS\,max} = 74.8°C \; (166.6°F)$

If all the Triacs are mounted on one H.S. - $\Sigma Pd = 42(6)(3.4)$
$= 859.32 \frac{BTU}{hr.}$

This is excessive for the 5305 heat sink (REF 20HP@240V pg 112)

∴ Assume there are three diodes per heat sink

$\Sigma Pd = 42(3)(3.41) = 429.66$

Assume 5305 H.S. $L = 9''$

$R_1 = \frac{L}{D} = \frac{9}{.5} = 18$, $R_2 = 4$

$F_{1-A} = 1.0 - .76 = .24$

	$\underline{T_{HS}}$	$\underline{\Sigma Pd} = 429.66$	
$L = 9''$	160°F	392.07	
B5305 H.S.	165	432.5	
	164	424	∴ $T_{HS} \cong 164.6°F$
	164.6	429.25	

$T_J = T_{HS} + Q\Sigma R = 164.6 + 42(.4 + .2)(1.8)$
$= 209.96\ (98.9°C)$

VII Continued - 20HP 240V

I_{RMS} / Leg = 51.9 amps

Using Two SC265 Triacs per Leg

I_{RMS} / Triac = $\frac{51.9}{2}$ = 26 amps

Pd / Triac = 26 watts.

T_{HS} max = $T_{J_{allow}} - \Sigma QR$

R_{J-C} = 1.10 °C/W R_{C-HS} = .4 °C/W

T_{HS} max = 105 − 26 (1.10 + .4)
= 66 °C (150.8 °F)

Assume Three Triacs per each 5305 Type heat sink

ΣPd = 26 (3) (3.41) = 265.98

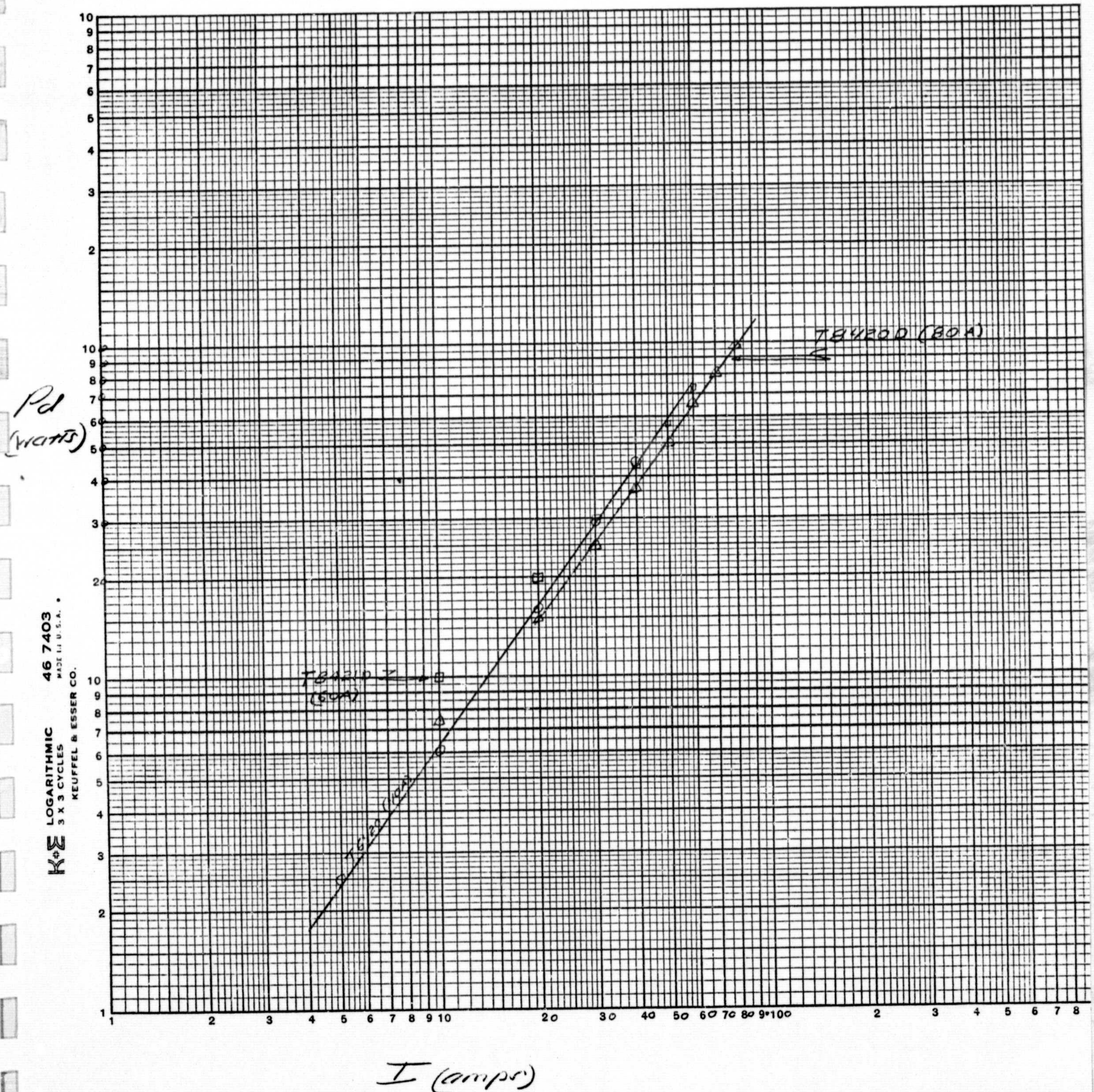
Assume L = 6"

$R_1 = \frac{6}{.5} = 12$ $R_2 = 4$

F_{1-A} = 1 − .73 = .27

T_{HS}	ΣPd = 265.98
140	175
150	229
155	257

∴ T_{HS} > 150.8 °F and is


TB4120D (80A)
TB4210 Z
(60A)
Pd
(watts)
I (amps)
K+E LOGARITHMIC
3 X 3 CYCLES
KEUFFEL & ESSER CO.
46 7403
MADE IN U.S.A.

Assume $L = 8''$

$F_M = .25$

	T_{HS}	$\Sigma P_d = 265.98$	
$L = 8''$	140	219.54	
type	145	252.89	$\therefore T_{HS} \cong 147°F$
5305	147	266.5	

$$T_J = T_{HS} + Q_{ER} = 147 + 26(1.5)(1.8)$$
$$= 217.2°F\,(102.8°C)$$

8/13/78 ①

Revised Thermal Analysis - Iveco Controllers

Assuming 80°F cooling air and ambient temperatures

I 1 HP - 240 volts -

I_{rms} / leg = 2.96 amps

Assuming SC240 Triac (G-E)

From GE data sheets - @ I_{rms} = 2.96 a, Power dissipation = 3.9 watts

T_j max = 100°C R_{j-c} = 2.2°C

REF G.E. - R_{C-HS} = 2.5°C/w with 3 mil mica washer & silicone grease.

$T_j - T_{HS} = Q \Sigma R_{th}$

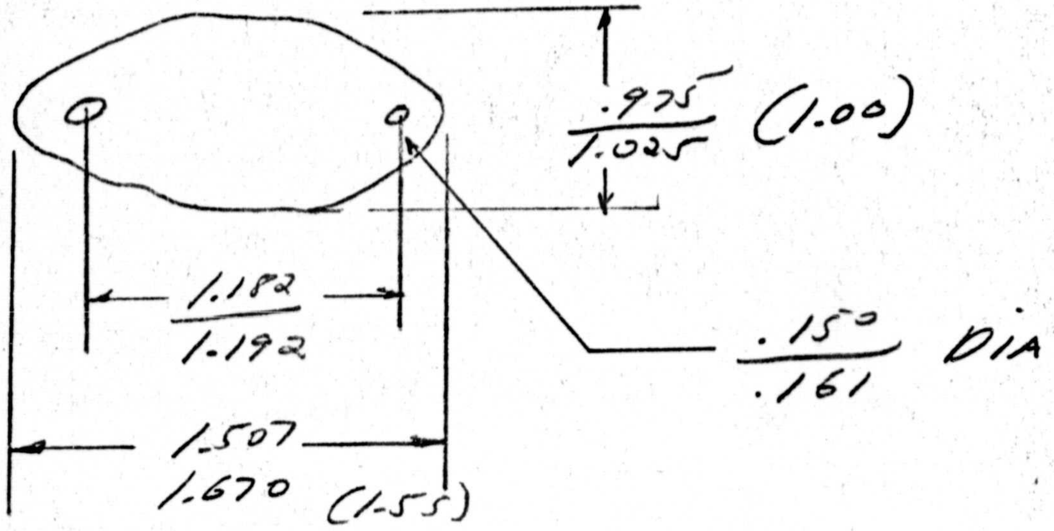
$T_{HS_{max}} = T_j - Q \Sigma R_{th}$

$= 100°C - 3.9w (2.2 + 2.5)$

$= 81.67°C$ (179°F) (max)

$\therefore \Delta T_{fluid-HS} = 179 - 80 = 99°F$

If The CHO-THERM heat sink elastomer is used -



$$\text{Area} = \left(\frac{1.00}{2}\right)\left(\frac{1.55}{2}\right)\left(\frac{4}{2}\right) - \frac{\pi}{4}(.155)^2(2)$$

$$= .737 \text{ in}^2$$

$$K_{mica} = .34 \text{ BTU/hr-ft}^2\text{-}^\circ F$$

$$R = \frac{L}{KA} = \frac{.003\,(144)\,(3.41)}{(12)(.34)(.737)(1.8)} = .27\ ^\circ C/\text{watt}$$

.003 " mica

$$K_{silicone\ grease} = .455 \frac{\text{BTU}}{\text{hr-ft}^2\text{-}^\circ F/\text{ft}}$$

@ .005 mil THK interface

$$R_{silicone} = \frac{.005\,(144)\,(3.411)}{(12)(.455)(.737)(1.8)} \times 2 = .68\ ^\circ C/\text{watt}$$

$$\Sigma(R_{mica} + R_{grease}) = .27 + .68 = .95\ ^\circ C/\text{watt}$$

$K_{\text{CHO THERM}} = 2.5 \frac{\text{BTU}}{\text{hr-ft}^2\,°F/ft}$

$$R = \frac{L}{KA} = \frac{.020\ (144)\ (3.41)}{12\ (2.5)\ (.737)\ (10)} = .247\ °C/\text{watt}$$

If two dry interfaces are considered. Then $\Sigma R = .247 + 2(.6) = 1.45\ °C/\text{watt}$

∴ The TO-3 Heat sink to Triac Case thermal Resistance will be in the Range of .95 °C/w to 2.5 °C/watt

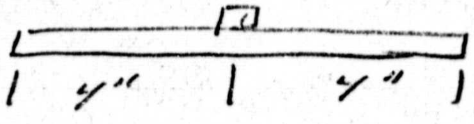
Again - if a .003 inch mica washer is assumed plus two greased joints @ .4 °C/w (REF GE) Then -

$$\Sigma R_{HS-C} = .4(2) + .27 = \underline{1.07}\ °C/\text{watt}$$

Assume the diodes are mounted in the center of the 6"×8"×4" housing 16 gauge steel $T = .060$ in THK.

$K = 27 \frac{\text{BTU}}{\text{hr-ft}^2\,°F/ft}$

Total power = 3.9 × 3 = 11.7 watts.



$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4}$$

Assume $\Delta T = 99°F$

$$h_c = .29\left(\frac{99}{8}(12)\right)^{1/4} = 1.01 \ \frac{BTU}{hr\text{-}ft^2\,°F}$$

$$h_R = .1714 \times 10^{-2}\, F_e F_a \left[\frac{T_1}{100} + \frac{T_2}{100}\right]\left[\left(\frac{T_1}{100}\right)^2 + \left(\frac{T_2}{100}\right)^2\right]$$

$F_a = 1.0 \quad F_e = .8$

$T_1 = 80°F = 540°F \quad T_2 = 179°F\ (639°F)$

$$h_R = .1714 \times 10^{-2}(.8)\left[5.40 + 6.39\right]\left[5.4^2 + 6.39^2\right]$$

$h_R = 1.13$

$$h_T = h_R + h_c = 1.01 + 1.13 = 2.14 \ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

$Q = h_c A \Delta T$

$$11.7(3.41) = 2.14\,\frac{(8 \times 6)}{144}\,\Delta T\,°F$$

$\Delta T°F = 55.9°F$

$$m = \sqrt{\frac{hc}{KA}} = \sqrt{\frac{(2.14)(6)(144)}{(27)(.060)(6)(12)}} = 3.98$$

$$Q = K m A \theta_o \operatorname{Tanh}(mL)$$

$$\frac{11.7}{2}(3.41) = 27(3.98)\frac{(6)(.060)}{144}\theta_o \operatorname{Tanh}\left[3.98\left(\frac{4}{12}\right)\right]$$

$$\theta_o = 85°F \quad (= T_{x=0} - T_f)$$

$$T_{x=L} = T_f + \frac{T_{x=0} - T_f}{\operatorname{Cosh} mL}$$

$$T_{x=L} - T_f = \frac{85°F}{\operatorname{Cosh}(3.98)\left(\frac{4}{12}\right)} = .495(85°F) = 42°$$

$\therefore$ Average drop $= \dfrac{85+42}{2} = 63°F$

$$h_c = .29\left[\frac{63°F}{8}(12)\right]^{1/4} = .904\ °F$$

$T_{fluid} = 80°F \quad - \quad T_{case\ mean} = 80 + 65°F$

$= (540°R) \quad\quad = 145°F\ (605°R)$

$$h_R = (.1714 \times 10^{-8})(.8)\left[5.40 + 6.05\right]\left[5.40^2 + 6.05^2\right]$$

$h_R = 1.03$

$h_T = 1.03 + .904 = 1.934$

$$m = \sqrt{\frac{hc}{KA}} = \sqrt{\frac{(1.934)(6)(144)}{(12)(27)(.060)(6)}} = 3.78$$

$$Q = \frac{11.7}{2}(3.41) = \frac{(27)(3.78)(6)(.060)}{}\theta_o \operatorname{Tanh}\left[3.78\left(\frac{4}{12}\right)\right]$$

$\theta_o = 91.86°F$

$T_{HS} = 80 + 91.86 = 171.86°F$

which is acceptable

If the radiation & convection inside the box is considered — and that $R_{C-HS} = 1.0°C/W$

Then $T_{HS\,max} = T_J - Q \Sigma R_{th}$

$= 100°C - 3.9W(2.2 + 1.2)$

$= 86.74°C \; (188°F)$

$\Delta T_{HS-fluid} = \theta = 188 - 80 = 108°F$ max.

Assume $\Delta T = 70°F$ $\quad T_f = 80°F = 540°R$ $\quad T_{HS} = 150°F = 610°R$

$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{70}{8}(12)\right)^{1/4} = .93$

$h_R = .1714 \times 10^{-2}(.8)\left[5.4 + 6.1\right]\left[5.4^2 + 6.1^2\right]$

$= 1.04$

Assume $h_{T_{eff}} = (h_R + h_c)(1.5) = [1.04 + .93][1.5]$

$= 2.955$

$m = \sqrt{\frac{hC}{KA}} = \sqrt{\frac{(2.955)(6)(144)}{(12)(27)(.06)(6)}} = 4.6785$

$Q = K m A \theta_o \operatorname{Tanh}(mL)$

$$\frac{11.7}{2}(3.41) = 27(4.6385)\frac{(.06\times 6)}{144}\,\theta_0 \tanh\left(4.6385\times\frac{4}{12}\right)$$

$$\theta_0 = 69.0$$

$$T_{x=L} - T_f = \frac{69}{\cosh\left(4.6385\times\frac{4}{12}\right)} = 27.79 = \theta_{x=L}$$

$$\theta_{mean} = \frac{69+27.79}{2} = 48.3$$

$$h_{c_{mean}} = .29\left(\frac{48.3}{8}(12)\right)^{1/4} = .846$$

$$T_f = 80^\circ F = 540^\circ R$$

$$T_{HS\ mean} = 80+48.3 = 128.3^\circ F\ (588.3)$$

$$h_R = .1714\times10^{-8}(.8)\left[5.883+5.40\right]\left[5.883^2+5.4^2\right]$$

$$= .987$$

$$h_T = (h_R+h_c)(1.5) = (.846+.987)(1.5) = 2.75$$

$$Q = h_c A\,\Delta T$$

$$11.9(3.41) = (2.75)\frac{(6\times 8)}{144}\,\Delta T$$

$$\Delta T_{mean} = 44.26^\circ F \qquad m = \sqrt{\frac{(2.75)(6)(144)}{12(27)(.06)(6)}}$$

$$m = 4.513$$

$$\frac{11.7}{2}(3.41) = 27(4.513)\frac{(.06)(6)}{144}\,\theta_0 \tanh\left[4.513\times\frac{4}{12}\right]$$

$$\theta_0 = 72.28$$

$$\theta_{x=L} = \frac{72.28}{\cosh(4.513\times 4)} = 30.60$$

$$\theta_{mean} = \frac{72.28 + 30.6}{2} = 51.44$$

Assumed ΔT mean	Calc h_{eff}	Calc θ_0 & θ_L		Calc θ mean	Calc ΔT mean $Q = h_c A \Delta T$ $\Delta T = \frac{Q}{A h_c}$
70°F	2.955	69	27	48	41.19
48.3	2.75	72.28	30.60	51.44	44.268
45°F	2.71	72.98	31.21	52.095	44.92

$$h_c = .29\left[\frac{45(12)}{8}\right]^{1/4} = .8312$$

$T_f = 80°F\ (540°R)$, $T_{Hi\ mean} = (80 + 45) = 585°R$

$$h_R = (.1714\times10^{-8})(.8)\left[5.85 + 5.40\right]\left[5.85^2 + 5.40^2\right]$$

$$h_R = .978$$

$$h_{eff} = (.8312 + .978)(1.5) = 2.71$$

$$\frac{11.7}{2}(3.41) = 27\,(4.480)\left(\frac{.06\times6}{144}\right)\theta_0 \operatorname{Tanh}\left[4.48\left(\frac{4}{12}\right)\right]$$

$$m = \sqrt{\frac{(2.71)(6)(144)}{12(27)(.06)(6)}} = 4.480$$

$$\theta_0 = 72.98$$

$$\theta_{x=L} = \frac{72.98}{\operatorname{Cosh}\left[4.48\times\frac{4}{12}\right]} = 31.21$$

$$11.9(3.41) = 2.71\,\frac{(6)(8)}{144}\,\Delta T$$

$$\Delta T = 44.92$$

$\therefore \quad \theta_0 \doteq 73°F$

$\therefore \quad T_J = T_{HS} + Q\Sigma R$

$T_J = 80 + 73 + 3.9(2.0 + 2.5)(1.8)$

$= 185.99°F \; (85.5°C)$

@ $T_J = 100°C \; (212°F)$

$T_{HS} = 179°F$ -

$\therefore \; T_{fluid\,max} = 179 - 73 = \underline{\underline{106}}°F$
@ $R_{C-HS} = \underline{\underline{2.5}}$

@ R_{CHS} @ 1.2 - 188°F

$T_{fluid\,max} = 188 - 73 = \underline{\underline{115}}°F$
@ $R_{CHS} = 1.2°C/W$

II 5 HP, 480 VOLTS -

Use SC245 $\quad R_{J-C} = 1.65°C/watt$

$I_{RMS} = 7.4$ a $\quad P_d = 9$ watts/Leg.

$T_J\,max = 100°C$

$T_{HS}\,max = T_J - Q\Sigma R$

$= 100°C - 9(1.65 + 2.5)$

$= 62.65°C \; (144.8°F)$

@ $R_{CHS} = 2.5\,°C/W$

(Non-isolated)

T_{HS} max $= 100°C - 9(1.65 + 1.2)$
$= 74.35°C\ (165.83°F)$
@ $R_{CHS} = 1.2$ °C/W

If first assume that
$\theta_0 = 144.8 - 80 = 64.8°F$ max

From graphs – (1st approx)
@ $L = 8''$ $h_c = 1.01$ $T_{HS} = 144.8 = 605°R$

$h_R = .1714 \times 10^{-2}(.9)[5.4 + 6.05][5.4^2 + 6.05^2]$
$= 1.16$

$h_T = 1.01 + 1.16 = 2.17$

$Q = h_c A \Delta T$

$A = \dfrac{Q}{h_c \Delta t} = \dfrac{9(3)(3.41)}{(2.17)(64.8)} = .654\ ft^2\ (94.3\ in^2)$

∴ 8 inch high need a 11.7" width
(Too much)

∴ need a heat sink, finned

Assume IERC section E103 – 1.5" long
$C = 24.0$

From "graph" $h_c = 1.54$

Considering convection only –

$(9)(3.41) = 1.54\ \dfrac{(24.0)(L)}{144}\ (64.8)$

$L = 1.845$

E 260 series, cost compared

To E103 - chk it out

Assume 5" Long heatsink

(section E103)

Fin Height - 1.688, Spacing - .68

$W = 1.688$, $L = 5.0''$, $D = .68$

$R_2 = \frac{W}{D} = \frac{1.688}{.68} = 2.48$

$R_1 = \frac{L}{D} = \frac{5}{.68} = 7.35$

From Chapman $F_A = 1 - .6 = .4$

@ T.R = 1.8 °C/W - 3" section -

5" section = $\frac{3}{5}(1.8) = 1.08$ °C/W

$\Delta T = QR = 27W(1.08) = 29$ °C (52°F)

Tsink = 80 + 52 = 132°F - 144 °F max allowable

Consider E 240 section

L = 5" TR = 4.6 °C/W

$R_{C5''} = 4.6\left(\frac{3}{5}\right) = 2.76$ °C/W

$\Delta T_{sink-amb} = QR = 27(2.76) = 74.52$ °C (134°F)

Tsink = 80°F + 134 = 214°F which is excessive -

∴ Assume 5" Long section E 103

$C = 24.0\ in^2/in$ & $\Delta T = 52$

$$h_c = .29\left[\frac{\Delta T}{L}\right]^{1/4} = .29\left[\frac{52}{5}(12)\right]^{1/4}$$

$h_c = .969 \qquad A = 24.0(5) = 120\ in^2$

$T_{HS} = 130°F\ (592°R) \qquad T_f = 80°F\ (540°R)$

$$h_R = .1714 \times 10^{-2} F_A\ \epsilon\left[\frac{T_1}{100} + \frac{T_2}{100}\right]\left[\left(\frac{T_1}{100}\right)^2 + \left(\frac{T_2}{100}\right)^2\right]$$

$$h_R = .1714 \times 10^{-2}(.4)(.9)\left[5.92 + 5.40\right]\left[5.92^2 + 5.40^2\right]$$

$h_R = .448\ @\ F_A = .4\ ;\ h_R = 1.12\ @\ F_A = 1.0$

$A_{FA=1.0} = 3.937(5) + 1.50(5)(2) = 34.69\ in^2$

$A_{FA=.4} = (1.5)(5)(11) = 82.5\ in^2$

$Q = (\Sigma h A)(\Delta T)$

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$$27(3.41) = \left[\frac{82.5(.448) + 34.69(1.12) + .969(24)(5)}{144}\right]\Delta T$$

$\Delta T = 69°F$

$T_{HS} = 80 + 69 = 149°F$

If a 6" Length is used—

$A_{FA=1.0} = 3.937(6) + 1.50(6)(2) = 41.62\ in^2$

$A_{\ \ "} = 1.5(6)(10) = 90\ in^2$

Then —

$$27(3.41) = \left[\frac{90(.448) + 41.62(1.12) + .939(24)(6)}{144}\right]\Delta$$

$$h_c = .29\left[\frac{\Delta T}{L}\right]^{1/4} = .29\left[\frac{55}{6}(12)\right]^{1/4}$$

$= .939$

$\Delta T = 59.7°F$

$T_{HS} = 80 + 59.7°F = 139.7°F$ which is acceptable — (144.8°F max allow. @ $R_{CHS} = 2$

$$R = \frac{\Delta T}{Q} = \frac{59.7}{(1.8)(27)} = 1.23°C/watt$$

3" section — $R = 1.8°C/w$

6" section — $R = 1.8\left(\frac{3}{6}\right) = .9°C/watt$

$\left[\therefore\right.$ 6" Long E103 section is Required — [have a 5°F to 25°F margin] $\left.\right]$

III 5 HP, 240 volts

14.8 amps per leg — use SC25C

$R_{J-C} = 1.6°C/w$ $P_d = 20$ watts/leg

$T_{J\,max} = 115°C$

Assuming $R_{CHS} = 2.5°C/watt$

$T_{HS\,max} = T_J - Q\Sigma R$

$= 115°C - 20(1.6 + 2.5) = 33°C$ (91.4

II Cont. - if assume 1.6" Long E 103 section

$\Delta T = 25°C\ (45°F)$

$h_c = .29 \left(\frac{\Delta T}{L}\right)^{1/4} = .29 \left(\frac{45}{1.66} \times 12\right)^{1/4}$

$h_c = 1.23 \frac{BTU}{hr\text{-}ft^2\text{-}°F}$

$h_{R\,FA=1} = .1714 \times 10^{-2} (.9) \left[5.4 + 5.85\right] \left[5.4^2 + 5.85^2\right]$

$= 1.10$

$h_R = .44 \quad FA = .4$

$A_{FA=1} = 3.937(1.6) + 1.50(1.6)(2) = 11.099\ in^2$

$A_{FA=.4} = 1.5(1.6)(10) = 24\ in^2$

$9(3.41) = \left[(1.23)(24)(1.6) + .44(24) + 11.099(1.10)\right] \frac{\Delta T}{144}$

$\Delta T\,°F = 63\,°F\ (35.1°C)$

(IERC has 30°C or 54°F rise)

If consider the back side of the fin

$A_{FA=1.0} = 3.937(1.6)(2) + 1.50(1.6)(2) = 17.40$

$9(3.41) = \left[1.23(24)(1.6) + .44(24) + 17.4(1.10)\right] \frac{\Delta T}{144}$

$\Delta T = 57°F - (31.67°C\text{ rise})$

which is very close to the IERC data point -

B

II Continued - (.5 HP, 480V)

E 193 section isolated

$\boxed{SC245}$ diodes P_d/leg = 9 watts

Assume R_{j-c} = 1.80 °c/w

R_{cHS} = .4 °c/w T_J max = 100°C

T_{HS} max = T_J - QΣR

= 100° - (9)[1.8 + .4]

= 80.2°C (176.4°F)

ΔT = 176.4 - 80 = 96.36 °F

Assume all diodes on one heat

sink - L = 5"; T_f = 80°F

P_1 = 3.937 + 1.688(2) = 7.313

P_2 = 1.688(2) + 1.50(8) = 15.38

REF. Chapman - D = .68

W = 1.500, L = 5"

$R_2 = W/D = \frac{1.50}{.68} = 2.21$

∴ F_{12} = .59

$R_1 = \frac{L}{D} = \frac{5}{.68} = 7.35$

∴ F_{11} = 1 - F_{12} = 1 - .59 = .41

A_{HS} = 24 - 3.937 = 20.063 inches

Using the Calculation program

$27(3.41) = 93.07$

T_{HS} °F	Σ
120 °F	45.8
150 °F	89.88
160 °F	105
155	97.8
153 °F	94.63
152 °F	93.04
151 °F	91.46

$\therefore T_{HS} \hat{=} 151.5$ °F

($\Sigma = 92.25$)

$\therefore T_J = T_{HS} + 9(1.8 + .4)(1.8) =$

$= 151.5 + 9(2.2)(1.8) = 187$°F (86°C)

If a <u>6 inch</u> Length E103 is used –

$R_2 = \frac{1.4}{D} = \frac{1.5}{.68} = 2.21$, $R_1 = \frac{6}{.68} = 8.82$

$F_M = 1 - .59 = .41$

T_{HS} °F	Σ
120	53.62
130	69.97
140	87.16
145	96.05
142	90.07
143	92.46

$\therefore T_{HS} = 143$°F

$T_J = 143 + 9(2.2)(1.8)$

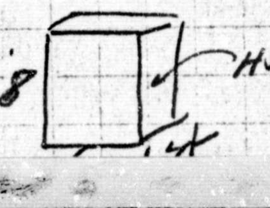
$= 178.6$°F ($\underline{\underline{81}}$ °C)

[$\therefore$ Use the 6" E103 section]

[Isolated diodes, one per line,

Three diodes mounted on the HS

6" x 8" x 4" case



see pg 208

If an $R_{CHS} = 1.2\,°C/W$ is assumed

$T_{HS\,max} = 115°C - 20(1.6+1.2) = 59°C$ (138.2°F)

$\Delta T = T_{HS} - T_f = 138.2 - 80 = \underline{58.2°F}$

If one considers the isolated case — $R_{J-C} = 1.75\,°C/W$ $R_{CHS} = .4\,°C/W$

$T_{HS\,max} = 115°C - 20(1.75+.4) = 72°C$ (161.6°F)
(isolated case)

& $\Delta T_{HS-f} = 161.6 - 80 = \underline{81.6°F}$

a) Consider non isolated case

$\Delta T_{HS-f} = 58.2°F$

TR - (E103 section) = 1.8 °C/W / 3 inch

Assume 8" Length. Pd = 60 watts

& $R_{HSf} = 1.0\,°C/watt$

$\Delta T = QR = 60(1.0) = 60°C$ (108°F)
excessive

$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{58}{8}(12)\right)^{1/4} = .89$

$h_R \cong .45$ @ $F_A = .4$ $h_R = 1.12$ @ $F_A = 1.0$

$A_{FA=1.0} = 3.937(8) + 1.50(8)(2) = 55.5\ in^2$

$A_{FA=.4} = 1.5(8)(10) = 120$

$$(60)(3.41) = \left[120(.45) + 55.5(1.12) + .839(24)(8)\right]\frac{\Delta T}{144}$$

$\Delta T\,°F = 106°F$ which is

b) excessive — (138°F max allowable)
i.e. $T_{HS} = 186°F = 106 + 80°F$

If Two diodes per line are used — (NON-isolated)

$$T_{c\,HS\,max} = 115°C - 10(1.6 + 1.2) = 87°C \ (\underline{\underline{188.6}}$$

$$\Delta T_{HSF} = 188.6 - 80 = 108.6°F$$

and the 8" Long E103 section is acceptable

Checking This @ $\Delta T = 108.6°F$

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{108}{8}(12)\right)^{1/4}$$

$h_c = 1.03$ BTU/HR·FT²°F

$T_f = 80°F\ (540°R)$; $T_{HS} = 188.6°F\ (648°R$

$$h_R = .1714\times10^{-2}(.4)(.9)\left[5.4^2 + 6.48^2\right]\left[5.4 + 6.48\right]$$

$$h_{R\,@\,FA=.4} = .501$$

$$(60)(3.41) = \left[120(.501) + 55.5(1.0) + 24(8)(1.03)\right]\frac{\Delta T}{144}$$

$\Delta T = 93°F$

$T_{HS} = 80 + 93 = \underline{173°F}$ (188.6°F max (Two diode) allowable)

$\therefore$ 8" Long section would theoritically be Long enough but there is unsufficient room for 6 diodes (i.e. $L = 1.507 \times 6 = 9.042"$)

c) Consider non-Isolated case $T_{HS\,max} = 138°F$ ($\Delta T = 58.0°F$) $\underset{(per\ leg)}{Pd} = 20$ watts, one diode per leg - one heat sink per diode, 4" Long E103 section

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{58}{4}(12)\right)^{1/4} = 1.05$$

$A_{FA=1.0} = 3.937(4) + 1.50(4)(2) = 27.75$ in2

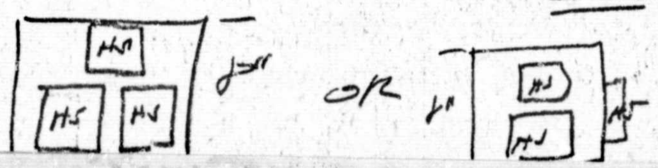
$A_{FA=.4} = 1.5(4)(10) = 60$ in2

$$(20)(3.41) = \left[60(.45) + 27.75(1.10) + 1.05(24)(4)\right]\frac{\Delta T}{14}$$

$\Delta T_{°F} = 61.8°F$

$T_{HS} = 80 + 61.8 = 141.8°F$ (S/B 138.0°F max

which means that three heat sinks, one per diode, 4" Long sections of E103 - use 8" x 8" Cave (based on $R_{C\text{-}HS} = \underline{\underline{1.2}}$ °C/watt)



5HP 240 volt case — (non-iso diodes)

a) Two non-isolated diodes per line - One 8" Long E103 (3 diode section, case 6x8"x4", HS mounted on the side - (will not fit)

b) One non isolated diode per line - Three 4" Long E103 section one per diode, case 8x8x6" all mounted on the front panel or 6x8x4 case with two mounted one the front panel and one on the side

---

5HP 240 volt - isolated case

From before - (pg 14)

a) One diode per line, $R_{J-C} = 1.75$

$R_{CHS} = .4$, $T_{HS}\ max = 161.6°F$

$\Delta T_{HS-f} = 161.6 - 80 = 81.6°F$

Assume E103 section — $L = 8"$

$T_f = 80°F$ (545°R); $T_{HS} = \underline{161.6}$ (701°R)

$$h_R = .1714 \times 10^{-2} (.4)(.9)\left[5.4+7.01\right]\left[5.4^2+7.01^2\right]$$

$h_R = .599$ @ $F_A = .4$

$h_R = 1.50$ @ $F_A = 1.0$

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left[\frac{81.6}{8}(12)\right]^{1/4} = .965$$

$A_{F_A=1.0} = 55.5 \text{ in}^2$ $\quad A_{(F_A=.4)} = 100 \text{ in}^2$

$$(60)(3.41) = \left[1.5(55.5) + .599(100) + .965(24)(5)\right]\frac{\Delta T}{144}$$

$\Delta T °F = 86.5 °F$

$T_{HS} = 80 + 86.5 = 166.5$ °F @ $R_{CHS} = .4$°c/w

which is very close to being acceptable

c) -: $\boxed{\text{5HP 240 volt - (isolated case) one diode per line, E103 section 8 inches long, all diodes on one section - Box 6x8x4 - HS on the side}}$

d) 5HP 240 volt - non isolated case

Forced convection -

Assume $Q = 90$ cfm

$$V = \frac{Q}{A} = \frac{90(144)}{(6)(4.5)} = 480 \text{ fpm}$$

Section Length = 1.507 X 3 = 4.5"
Assume a 5" Long section
Three diodes on one section –

$$\Delta T°F \text{ Rise} = \frac{Q_H}{mc_p} = \frac{60 W (3.41)}{(90)(60)(.24)(.0148)}$$

$\Delta T°F$ Rise = 10.6°F

With 80°F inlet air – T_{out} = 90.6°F

T_f mean = 85°F

T_{HS} max = 91.4°F @ R_{CHS} = .25 °C/W
= 138.2°F @ R_{CHS} = 1.2 °C/W

Taking the latter assumption – ie
R_{CHS} = 1.2°C/W –

Assume T_{HS} = 138.2°F

$$T_{mean} = \frac{138.2 + 85}{2} = 116 °F$$

μ = .047 , k = .0161 , $\frac{c_p \mu}{k}$ = .7 = N_{Pr}
ρ = .0695

$$N_R = \frac{VD\rho}{\mu} = \frac{(480)(60)(5)(.0695)}{12\ (.047)}$$

= 17,745

The flow is laminar

$$h_c = \frac{K}{L}(.664)(N_{Re})^{1/2}(N_{PR})^{1/3}$$

$$h_c = \frac{(.0161)(12)(.664)}{5}(13740)^{1/2}(.7)^{1/3}$$

$h_c = 3.03$ BTU/hr-ft^2°F

$Q = h_c A \Delta T$ Assuming section

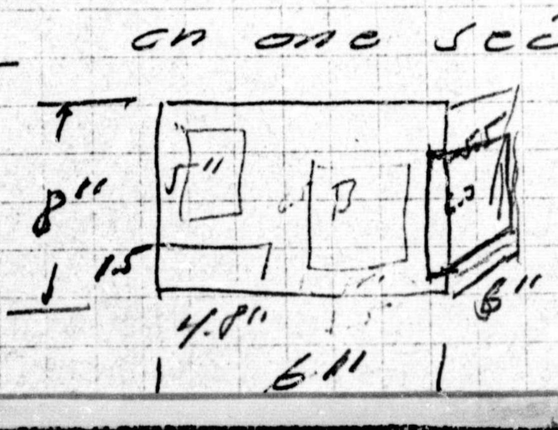
E102, $C = 30.7$ in^2/in

$$60(3.41) = 3.03\frac{(30.7)(5)}{144}(\Delta T)$$

ΔT°F $= 50.2$°F

$\therefore$ $T_{HS} = 85 + 50.2 = 135.2$°F which is acceptable -

[$\therefore$ Could use one fan, one 5" Long E102 section, non isolated diodes One diode per Line, all diodes on one section - case size]



8" × 6" × 6"

Continued -

5HP 240 volts, I = 14.8a/leg

SC 250, isolated, $R_{J-C} = 1.75$

Pd/leg = 20 watts, Assume $R_{CHS} = .4$

$T_{HS\,max} = T_J - Q\Sigma R$

$= 115°C - 20(1.75+.4) = 72°C$ (161.6°F)

One diode per line

Assume all diodes on a 6" E103

Long section

$\Sigma Q = 60(3.41) = 204.6$

THS	ΣQ
150	105
170	143
180	163
190	184
200	206

∴ THS ≈ 200°F which is unacceptable -

Assume 8" Long section (E103)

THS	ΣQ
150	134
160	158
170	183
180	209

∴ THS ≈ 180°F which is still unacceptable

Assume L = 1.5 Long section (E103)
one diode per section

$\Sigma Q = 20(3.41) = 68.1$

THS	ΣQ	THS	ΣQ	THS	ΣQ
120	16.4	180	50.3	210	70.2
150	32.3	190	55.7	205	66.7
170	44.1	200	63.3	206	67.4

Assume $L = \underline{4''}$ E103 section

one diode per line –

T_{HS} °F	ΣQ
120	37.8
140	61.5
145	67.8
142	64
143	65.3
146	69.0
145.5	68.04

$T_{HS} = 145.5$ °F

$T_J = 145.5 + 20(3.15)(1.4)$

$= 232.9°F(\underline{106°C})$

Assume $L = 3''$ E103 section

one diode per line –

T_{HS} °F	ΣQ
150	58.09
160	68.4

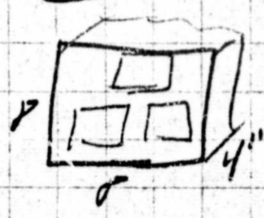
$\therefore T_J = 160 + 20(3.15)(1.4)$

$= 237.4°F(114°C)$

$\therefore$ use 4" Long E103 sections

one diode per H.S. (isolated)

(8" × 8" × 4" box)



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IV 10 HP - 480 volts -

a) 13 amps per Leg - SC250

P_d = 17.0 watts per Leg.

Could use the same options as for the 5HP - 240 volt condition.

V 10 HP - 240 volts

a) I_{rms} = 25.9 amps per Leg

Using SC 265 P_d = 26 watts

R_{J-C} = .95 °C/watt - (non isolated diodes)

$T_{HS(max)} = T_J - Q \Sigma R$

Assume R_{CHS} = 1.2 °C/W

$T_{HS(max)}$ = 115°C - 26(.95 + 1.2)

= 59.1 °C (138.4 °F)

$$\Delta T_{inlet-outlet} = \frac{Q_H}{mC_p} = \frac{26(3)(3.41)}{(80)(60)(.24)(.0148)}$$

= 13.8 °F

$$T_{mean\ inlet-outlet} = \frac{80 + 93.8}{2} = 86.9\ °F$$

(see A3-24)

$$T_{\substack{air\text{-}HS \\ mean}} = \frac{138.4 + 86.9}{2} = 113°F$$

$k_{air} = .0160, \ \mu = .0465$

$\rho = .0695 \quad N_{PR} = .7$

$V = 480 \text{ fpm}$ Assume $L = 6"$

$$N_R = \frac{(480)(60)(6)(.0695)}{(12)(.0465)} = 21,502$$

$$h_c = \frac{(.0160)(.664)(21,500)^{1/2}(.7)^{1/3}(12)}{6}$$

$h_c = 2.77$ Assume E102,

$C = 38.7$

$Q = h_c A \Delta T$

$$26(3)(3.41) = 2.77 \frac{(38.7)(6)}{144} \Delta T°F$$

$\Delta T°F = 59.5°F$

$\therefore T_{HS} = 86.9 + 59.5 = 146.4°F$

which is acceptable considering radiation was neglected.

$\therefore$ use 6" Long E102 section, non isolated diodes, 3 diodes per section; one fan. Case size $8" \times 6" \times 6"$

b) 10 HP - 240 volts

I_{RMS} = 25.9 a, per leg

Using SC 265 P_d = 26 watts/leg

Isolated case - R_{J-C} = 1.1 °C/W

R_{C-HS} = .4 °C/watt.

$$T_{HS(max)} = T_J - QER$$

$$= 115°C - 26(1.1 + .4) = 76°C\ (168.8°F)$$

ΔT HS-fluid = 168.8°F - 80 = 88.8°F

If an IERC E103 section is assumed - one 3" section per diode -

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{88.8}{3}(12)\right)^{1/4}$$

$$= 1.26 \frac{BTU}{hr\text{-}ft^2\ °F}$$

T_A = 80°F (540°R) T_{HS} = 168.8°F (628.8°R)

$$h_R = .1714 \times 10^{-8}(.9)[5.4 + 6.29][5.4^2 + 6.29^2]$$

h_R = 1.239 (FA=1.0) $A_{FA=1.0}$ = 11.059 $\left(\frac{3}{1.6}\right)$ = 20.8

h_R = .496 (FA=.4) $A_{FA=.4}$ = 24 in² $\left(\frac{3}{1.6}\right)$ = 45

$$26(3.41) = [1.239(20.8) + .496(45) + 24(3)(1.26)]\frac{\Delta T}{144}$$

ΔT = 91.9 °F (2°F to high)

If a 4" Long section is assumed -

Continued –

10 HP – 240 volts – 25.9 a/leg

Use SC265 <u>isolated</u>

Pd – 26 watts/leg

$R_{J-C} = 1.10\ ^{\circ}C/W$, $R_{CHS} - .4\ ^{\circ}C/W$

$T_{HS} = T_J - \Sigma QR$

$= 115^{\circ}C - 26(1.10 + .4) = 76^{\circ}C$
$(168.8^{\circ}F)_{max}$

If a E103 section 5" Long is assumed – one <u>isolated</u> <u>diode</u> per section $\Sigma Q = 26(3.41) = 88.66$

T_{HS}	ΣQ
160	105
155	97.82
150	89.88
149	88.32

$\therefore T_{HS} = 149^{\circ}F$
$L = 5.0"$

$T_J = 149 + 26(1.5)(1.8)$

$= 219^{\circ}F\ (104^{\circ}C)$

If a E103 section 4" Long is assumed – one isolated diode per section

T_{HS}	ΣQ
160	87.50
161	88.85

$T_{HS} = 161^{\circ}F$
$L = 4.0$

$T_J = 161 + 26(1.5)(1.8)$

$= 231.0^{\circ}F\ (110.6^{\circ}C)$

Checking the drop down the 5" Long fin — $Q = h_{eff} A \Delta T$

$2\Delta T = 149 - 80 = 69°F$

$Q = 26$ watts

$A_f = 24 - 3.937 = 20.063 \text{ in} \times 5 \text{ in}$

$$26(3.41) = h_{eff} \frac{(20.063)(5)}{144}(69)$$

$h_{eff} = 1.84 \ \text{BTU/hr-ft}^2\text{-°F}$

$$Q = k\, m\, A_{cs}\, \theta_0 \tanh(mL)$$

$$m = \sqrt{\frac{hL}{k A_{cs}}} = \sqrt{\frac{(1.84)(144)(20.063)}{(90)(1.517)\ (12)}} = 1.80$$

$$26(3.41) = 90(1.80)\frac{(1.517)}{144}(\theta_0) \tanh\left[1.8\frac{(2.5)}{12}\right]$$

$\theta_0 = 144.9$ (close to 149°F)

Drop down the Length of the fin — $T_{x=L} = T_f + \dfrac{T_{x=0} - T_f}{\cosh mL}$

$$T_{x=L} - T_f = \frac{149°F}{\cosh mL} = \frac{149}{\cosh\left[1.8\left(\frac{2.5}{12}\right)\right]}$$

$= 139°F$

∴ have a 10°F drop down the length of the fin — (i.e. to each end)

∴ Use The 5" Long E103 section
one isolated diode per section
Box size - 8"x10"x4"

VI 20 HP - 480 volts

Irms / leg - 25.9 amps
Use SC 265, Pd = 26 watts per leg -
i.e. The same as The 10 HP - 240 volt
Condition - use the same configuratio

VII 20 HP - 240 volts -

Irms / leg - 51.9 amps

a) Consider That Two diodes per Leg, isolated SC 265, are used in parallel - Irms / diode = 25.9 amps
& could use The same Cooling configuration as in VI except have Two diodes per HS.

VIII 30 HP - 480 volts

a) I_{RMS} = 38.9 amps / Leg - one diode

∴ Use a SC265 - Pd / leg

= 44 watts T_J = 115°C max

R_{J-C} - 1.10 °C/w   Assume R_{CHS} = .4 °C/w

$T_{HS}\,max = T_J - Q\Sigma R$

$= 115°C - 38.9[1.1 + .4] = 56.65°C$
$= (133.97°F)$

Assume E103 section L=6"

$\Sigma Q = 44(3.41) = 150.04$

T_{HS}	ΣQ
120	53.63
200	206.16
150	105
160	123
170	143
180	163
175	153
174	151

∴ T_{HS} = 173.5°F

which is excessive

b) Assume an E133 section and

Two Diodes per Leg

i.e. 38.9/2 = 19.45 amps / Diode

Assume SC260, isolated, Type diode

@ 19.45 amps - Pd = 21 watts/diode

R_{J-C} = 1.55°C/W R_{CHS} = .4°C/W

T_J max = 115°C

$T_{HS_{max}} = T_J - Q\Sigma R$

$= 115 - 21(1.55 + .4) = 74°C$
(165°F)

Assume E103 section 5" Long

$\Sigma Q = 21(2)(3.41) = 143.22$

T_{HS}	ΣQ
120	45.8
160	105
170	122
180	139.87
185	148.7
182	143.4

∴ T_{HS} = 182°F which is still excessive

Assume E103 section 6" Long

T_{HS}	ΣQ
120	53.63
170	143.37

∴ T_{HS} = 170°F - still excessive -

c) Assume Two diodes per line of the SC 265 Type - [illegible]

√ = 19.45 amps Pd = 18 watts/diode

$T_{HS_{max}} = T_J - Q\Sigma R$

$= 115°C - 18[1.1 + .4] = 88°C$
(190.4°F)

Assume E103 section 5" Long

$Pd_{HS} = 18(2) = 36$ watts

$\Sigma Q = 36(3.41) = (122.76)$

T_{HS}	ΣQ
120	45.8
160	105
170	122.58

$\therefore T_{HS} = 170°F$

$T_J = 170°F + 18[1.1 + .4][1.8]$
$= 218.6°F \ (103°C)$

∴ Could use Two diodes per line isolated Type SC 265, E103 Section - 5" Long - Box size 8"x10"x4" (No Longer) Three heat sinks Req'd.

IX 30 HP - 240 volt condition -

I_{rms} / Leg = 77.8 amps.

a) Assume Three SC265 diodes per line - I_{rms}/diode = 25.9 a

Pd/diode = 26.0 watts

T_J max = 115°C

$T_{HS\,max} = 115 - 26[1.1 + .4] = 76°C \ (168.8°F)$

Assume 6" Long E103 section –

$$\Sigma Q = 26.0(3)(3.41) = 265.98$$

T_{HS}	ΣQ
200°F	206
220	251
225	263

∴ $T_{HS} > 225°F$ which is excessive; 168.8°F max allowable.

Consider E320 section

$P_1 = 4.50 + 1.40(2) = 7.3$ ✓

$P_2 = 1.40(18) = 25.2$ ✓

$W = 1.40 \quad L = 6" \quad D = .30$

$R_1 = \frac{L}{D} = \frac{6}{.3} = 20 \qquad R_2 = \frac{W}{D} = \frac{1.4}{.3} = 4.6$

∴ $F_{1\text{-}2} = .8$

$F_N = 1 - F_{1\text{-}2} = 1 - .8 = .2$ ✓

$A_{t/in} = 32.3 - 4.5 = 27.8$

Assume $L = 6"$

$$\Sigma Q = 265.98$$

T_{HS}	Q
170	168.23
180	191
190	216
200	241
210	267.7

∴ $T_{HS} \simeq \underline{210°F}$

which is excessive

If four diodes per line are considered - E300 $\overset{6'' \text{ Long}}{\wedge}$ Type H-5 -

I_{RMS} / diode = $\frac{77.8}{4}$ = 19.45 amps

Pd / diode = 18 watts/diode

$T_{HS\,max} = T_J - Q\Sigma R$ — 6" long

$= 115 - 18(1.1 + .4) = 88°C$

$= \underline{190°F}$

$\Sigma Q = 18(4)(3.41) = 245.52$

THS	EQ
~~190~~	~~259.73~~
~~192~~	~~265.92~~
180	192
185	204
192	221
200	241
202	246

∴ THS = 202°F

which is still a bit high -

Assume a E360 section - 6" Long - 4 SC265, isolated, diodes per line -

$P_{1\,FA=1.0} = 6.500 + 1.6(2) = 9.7$

$P_{2\,FA=4} = 1.6(20) = 32$

$W = 1.60, \quad L = 6.0, \quad D = .4$

$R_1 = \frac{L}{D} = \frac{6.0}{.4} = 15, \quad R_2 = \frac{W}{D} = \frac{1.6}{.4} = 4$

$\therefore F_{1\text{-}2} = .76$

$F_B = F_A = 1 - F_{12} = 1 - .76 = .28$

$A_f / \text{in} = 43.2 - 6.5 = 36.7$

$\Sigma Q = 218(4)(3.41) = 245.52$

T_{HS}	ΣQ
150	170.85
160	201.41
170	233.14
190	299
180	266.00
179	262.66
179.5	264.3
173.7	245.17

$\therefore T_{HS} = 173.7°F$

$T_J = 174 + 18(1.5)(1.8)$

$= 222.6°F (\underline{105}°C)$

∴ Could use four SC26T diodes per line, isolated, Three E360 sections each 6" Long - 4 diodes ea

Box Size 15 × 15" × 4"

Considering forced convection

I - 20 HP 240 volts

a) Assume two diodes per Leg, isolated SC 265 Type I_{rms}/Leg = 51.9 a

Pd / diode @ 2 per Leg = 26 watts

@ 26 amps per diode

Consider isolated stud types

SC265 - R_{J-C} = .95 °C/W

R_{CHS} - .4 °C/W

$T_{HS\,max} = T_J - Q \Sigma R$

$= 115 - 26(.95 + .4) = 79.9°C$

(175.8°F)

Total power dissipat = 26(6)(3.41)

= 531.96 $\frac{BTU}{hr}$

$\Delta T°F = \frac{.236\, W}{.Q \rho} = \frac{(.236)(26)(6)}{90(.068)} = 6°F$

∴ Rise is negilgable

& $T_{mean\,max} = \frac{83 + 176}{2} = 130°F$

$K = .0165$, $\rho = .0672$, $\mu = .048$,

$\mu_{PR} = .7$ $T_a = 83°F$

Trying E101 section L = 5"

$P_{fin\,in^2/in}$ = 26.9 in^2/in

Using the TI-59 program -

THS	ΣQ
150	189.28
170	245.78
190	302
250	471
260	500
280	556

∴ The THS is ~ 270°F which is not acceptable.

If L = 10" E 101 section

THS	ΣQ
150	267.6
200	467
205	567
215	527

∴ the THS is ~ 213°F – not acceptable

Trying a E102 section

L = 6" P_f = 38.7 in²/in

THS	ΣQ
150	298
200	520
210	565
205	543
202	529
203	534

∴ THS @ 203°F is still not acceptable

Trying a E102 section

8" Long –

THS	ΣQ
170	447
180	498
185	524

∴ THS ≅ 187°F and is still not acceptable

Trying a E102 Section - 10" Long

THS	ΣQ
150	385.1
✓ 180	557
175	528
176	534°F

∴ Would need a 10" Long E102 section

Six diodes on the section -

Trying a E613 section

$L = 6"$ $P_f = 61.3$

THS	ΣQ
✓ 150	472
✓ 160	543
✓ 155	507
157	521
158	528

∴ $T_{HS} = 158°F$

$T_J = 158 + 26(.95+.4)(1.8)$
$= 221°F (\underline{\underline{105°C}})$

If the RCA Triac is considered - # T 8411 - one per Leg -

$$I_{rms} = \frac{20(746)}{1.73\,(240)(.8)(.866)} = 51.9 \text{ amps.}$$

$P_d = EI = 1.5(51.9) = 77.85$ watts

Assume $T_{J\,max} = 150°C$

$R_{J-C} = .30°C/W$ $R_{CHS} = .4°C/W$

$T_{HS\,max} = T_J - QER$

$= 150 - 77.85(.35 + .4) = 91.6°C$
(197°F)

Assume all the diodes are mounted on one heat sink

Total dissipation = 77.85 (3)(3.41)

= 796.41 BTU/hr.

Assuming a E613 section L = 6"

T_{HS}	ΣQ
180	684
190	754
200	825
195	789
196	796

∴ THS is 196°F and the H.S. is marginally acceptable

II 30 HP 480 volts

a) Assume one diode SC265 per Leg, Pd/Leg = 44 watts @ 38.9a
isolated stud

$T_{HS\,max} = T_J - QER$

$= 115 - 44(.95 + .4) = 55.6°C$
(132°F)

$\Sigma Q = 44(3)(3.41) = 450.12$

Assume E613 section $L = 6"$

$P_{f/in^2} = 61.3$

THS	Q
120	260
150	472
145	437
147	451

$\therefore$ THS = 147°F which is unacceptable

Assume ~~E~~ E615, $L = 6"$ section

$P_{f/in^2} = 71.4$

THS	Q
140	468
135	427
137	443
137.5	447
138	451.7

$\therefore$ THS is 138°F ~~a~~ would not be acceptable

~~Box Size - 8" x 10" x 6"~~

Assume E615" section - 7" Long

THS	ΣQ
120°F	328
130	417
138	487
135	461
134	452

$\therefore$ THS = 134°F which is still unacceptable

37A

Assume EG05 section—

L = 6"   Pt/no = 87.9

THS	EQ
130	442
135	489
132 –	461
131.5 –	456
130.5	– 447

∴ THS = 131°F

6" Long section

one diode per Leg SL265 - stud no.

One heat sink

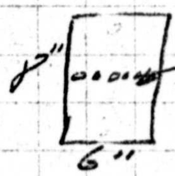
Box size – 8" × 10" × 6"

1) 1 HP 240/280 volts -

Diode G.E SC 240 - one/leg
(Pg 9) isolated - 400V - 2.58
600V - 2.94
(TO-3)

Heat Sink - none

Case Size - 6 x 8 x 4" - $6.40
Cover - .86
$7.26



Q1/3 mounting holes

2) 5 HP - 480 volt.

Diode G.E - one/leg SC245 - TO-3
isolated - $2.98 ea.

One E103, 6" Long H.S.

Section all three diodes mounted on the heat sink

(Pg 13C)

Case Size 8" x 6" x 4" - 6.40
Cover .86
$7.26

H.S. - #6 Holes - Total of 6 REQ'D for the Transistors and two for mtg -

[HS - E103 - 6" Long - Anodized - 8 - .150 holes -

3) 5HP 240 VOLT-

<u>One</u> <u>isolated</u> SC 250 diode

per Leg — $2.79

HS [<u>Three</u> heat sinks REQ'D
each - E103 - 4" Long - 4 - .150
DIA Holes per sink

Box size - 8" x 8" x 4 — 7.48
Cover — 1.10
$8.58

Need Three clearance
holes - 1.75 dia ea in the box

4) 10 HP 480 VOLT - (SC250 isolated TO3)
Same as 5 HP 240 VOLT case
Except Diode cost - $3.16/leg

5) 10 HP 240 VOLT
SC 265 - TO-3 isolated - $4.24 ea
<u>One</u> <u>diode</u> per leg
<u>Three</u> <u>heat</u> <u>sinks</u> REQ'D
HS - # E103 - 5" Long - 4 #.150 DIA HOLES
PER SECTION
Box Size - 8" x 12" x 4" - $9.72

5) Continued

Cover - 9.72
1.38
$11.10

Need Three 1.75 DIA clearance holes

6) 20HP - 480V

Same as 10 HP & 240 VOLT

One diode per Leg isolated, TO-3 - 5.1? / Leg

7) 20HP - 240 VOLTS

a) Two SC265 diodes, isolated, TO-3 per Leg.

Diode cost - 4.24 x 2 = $8.48/Leg

Three heat sinks, same as 5 & 6 except - 6 #.150 DIA holes per Leg

HS ⇒

b) Forced Convection

Σ FAN COST:
- Fan cost —
- Grille inlet —
- " outlet —
- Transformer Δ —
- Large hole in box —

Case Size

Two Diodes / Leg —

SC265 - Stud, Isolated - "

E613 Section - L = 6"
One section Req'd - 4 cut outs
for mounting & Three 1/4" Dia. Diode
Holes

8) 30HP - 480 Volts
a) Free convection -
Two SC265, TO-3, Isolated diode
per Line - 1C 5.14 (2) = 10.28/Line

H.S. ⇒ E103 - 5" Long - Three Req'd
Six - .150 dia Holes

Box Size 8" x 12" x 4" — 9.72
Cover — 1.38
$11.10

(Six 1.75 Dia cutouts
in the Box.)

9) b) Forced convection

≤ Fan costs —

HS - E605 section - L = 6"
Four mtg cutouts - Three 1/4 Dia Holes.

CONFIG	I_{RMS} PER LEG (AMPS)	Pd PER LEG (WATTS)	* DIODE TYPE ((COST))	# DIODES PER LEG (COST)	Pd PER DIODE	H.S. TYPE (COST) (EA.)	LENGTH (in)	T of HS	$R_{\theta j\text{-}c}$ (°C/W)	Pd PER H.S. (WATTS)	TOTAL # H.S.	BOX & COVER
1HP 240V	2.96	3.9	SC240 $2.58	1	3.9	NONE	8"	179°F	2.40	11.7	NONE	6"x8"x $7.26
5HP 480V	7.4	9	SC245 $2.98	1	9	E103 $3.08	6"	179°F	1.80	27	1	6"x8"x $7.26
5HP 240V	14.8	20	SC250 $2.79	1	20	E103 $2.31	4"	146°F	1.75	20	3	8"x10"x
10HP 480V	13.0	17	SC250 $3.16	1	17	E103 $2.31	4"	<146°F	1.75	17	3	8"x10"x
10HP 240V	26.0	26	SC265 $4.24	1	26	E103 $2.75	5"	149°F	1.10	26	3	8"x10"x $11.10
20HP 480V	26.0	26	SC265 $5.14	1	26	E103 $2.65	5"	149°F	1.10	26	3	8"x10"x $11.10
20HP 240V	51.9	52	SC265 $4.24	2	26				1.10	52	3	
30HP 480V	38.9	36	SC265 $5.14	2	18	E103 $2.75	5"	170°F	1.10	36	3	8"x10"x $11.10
30HP 240V	77.8	72	SC265 $4.24	4	18	E360 $4.88	6"	173.1°F	1.10	72	3	15"x15"x

[T fluid = 80°F]

J Cook

Re Run of The
PRIOR calculations considering
T_f max = 100°F
I_{rms} / Leg = 2.96 amps
SC 240 reqd - one per Leg.
P_d = <u>3.9</u> watts / Leg - T_j max = 100°C
R_{j-c} = 2.40 °C/W, R_{CHS} = .4°C/W
T_{HS}max = T_j - QER = 100 - 3.9 [2.4 + .4]
= 89.1°C (192°F)
Assume no heat sink except The
steel Can -
Assume L = 4" (01) T°F = 100 (02)
P_1 = 6.0" (03) P_2 = FA=N=1 = 6.0" (04)
FA=1.0
Fn = 1.0 (05) Af/s-inch = 6.0 (06)

ΣQ = 3.9 (3.41)(3) = 39.897

T_{HS}	ΣQ
120	10.31
140	22.47
150	29.083
160	36.033
170	43.31
165	39.63

∴ T_{HS} ≅ 165°F

$$Q = K m A_{cs} \theta_0 \operatorname{Tanh}(mL)$$

$h_c = 1.08$ (RCL 12)

$h_{R_{FA=1.0}} = 1.287$

$$m = \sqrt{\frac{hC}{KA}} = \sqrt{\frac{(2.367)(6)(144)}{(12)(27)(.06)(6)}} = 4.186$$

$$\frac{3.9(3)(3.41)}{2} = 27(4.186)\frac{(.06)(6)}{144}\theta_0 \operatorname{Tanh}\left[4.186\left(\frac{4}{12}\right.\right.$$

$\theta_0 = 79.83$ °F

$\therefore T_{HS} = 100 + 79.83 = 179.83$ °F

Drop down the fin –

$$T_{x=L} - T_f = \frac{\theta_{x=0}}{\operatorname{Cosh} mL} = \frac{79.83}{\operatorname{Cosh}\left[4.186\left(\frac{4}{12}\right)\right]} = 37.$$

$\therefore T_{HS} @ x=L = 137.26$

Drop $= 179.83 - 137.26 = 42.57$

$$T_{HS}\ \text{mean} = \frac{179.83 + 137.26}{2} = 158.5 °F$$

$\therefore \Delta T$ mean $= 58.5$

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{.25} = \left(\frac{58.5}{8}(12)\right)^{1/4} .29 = .887$$

$$h_R = .1714 \times 10^{-2} (.9) \left[\left(\frac{T_1}{100}\right)^2 + \left(\frac{T_2}{100}\right)^2 \right] \left[\frac{T_1}{100} + \frac{T_2}{100} \right]$$

$T_1 = 100\,^{\circ}F = 560\,^{\circ}R$

$T_2 = 158.5 + 460 = 618.5\,^{\circ}R$

$$h_R = .1714 \times 10^{-2} (.9) \left[5.6 + 6.185 \right] \left[5.6^2 + 6.185^2 \right]$$

$$= 1.265$$

$h_T = h_R + h_C = .887 + 1.265 = 2.153$

$Q = h_T A \Delta T$

$$3.9 (3)(3.41) = 2.153 \frac{(8)(6)}{144} \Delta T$$

$\Delta T = 55.59$

$\therefore T_{HS} = 100 + 55.59 = 155.59\,^{\circ}F$ (in con)

? (18.4257?)

$$\therefore T_{HS\,max} = 155.59 + \frac{37.26}{2} = \underline{\underline{174.2\,^{\circ}F}}$$

which is very close to the 179.83 in a prior calculation

$$\therefore \underline{\underline{T_J}}\,max = 174.2 + 3.9 (2.8)(1.8) = 193.8\,^{\circ}F$$
$$= \underline{\underline{89\,^{\circ}C}}$$

which is acceptable considering that radiation & convection inside the box was ignored –

II 5 HP, 480 volts

a) I_{rms}/Leg - 7.4 amps

Using - SC245 Type - Pd/Leg = 9 watts

R_{J-C} = 1.8°C/watt (isolated TO-3)

T_{HS} max = $T_J - \Sigma QR$ = 100°C - 9(1.8+.4)

= 80.2°C (176.36°F max)

One diode per line

Assume 1, E103 section - 6" Long

all the diodes mounted on the heat sink -

$\Sigma Pd = 9(3)(3.41) = \underline{92.07}$

For a E103 section - ($100°F = T_F$)

$P_1 = 7.313$, $P_2 = 15.30$, $F_H = .41$

A f/in = 20.063

$\underline{T_{HS}}$	$\underline{\Sigma Q}$ (92.07)
120°F	25.13
130°F	40.18
140°F	56.29
150°F	73.36
180°F	129.6
170	110.0
165	100.5
160	91.28
161	93.13
160.5	92.21

$\therefore T_{HS} = 160.5°F$

$T_J = T_{HS} + Q\Sigma R$

= 160.5 + 9(2.2)(1.8)

= 196.14°F (91.1°C

If a E103 section is used -

3 diodes per section - $L = \underline{7''}$

THS	EQ (92.02)
150	83.89
✓ 155	94.02
153	89.94
154	91.97
154.5	92.99

$T_J = 154.5 + 9(2.2)(1.8)$

$= 190.14°F (\underline{87.85°C})$

If a E103 section is used
3 diodes per section - $L = 8''$

THS	EQ (92.02)
150	94.26
149	92.02

$\therefore$ THS = 149°F

$T_J = 149 + 9(2.2)(1.8)$
$= 184.64°F (\underline{84.8°C})$

$\therefore$ Use the 7" Long E103 section - Concentra

Box size 6" x 8" x 4"

(Cont page 47A)

III <u>5HP, 240 volts</u>

a) Irms/Leg = 14.8 a - Pd/Leg = 20.0 watt

Diode Type - SC250 (TO-3 isolated)

$R_{J-C} = 1.75\ °C/W$ — $R_{CHS} = .4\ °C/W$

$T_{HS\,max} = T_J - QER = 115°C - 20(1.75 + .4)$
$= 72°C\ (161.6°F)$

(Cont. pg 48)

5 HP 480 volt Continued –

Irms / Leg = 7.4 a – using an
SC 250 diode – pd / Leg = 8.0 watts
R_{J-C} = 1.75 °C / watt – R_{CHS} = .4 °C/w
T_{HS} max = 115 °C – 8 (1.75 + .4) = 97.80 °C
(208.04 °F)

a) Assume E103 section – 2" Long – (3 HS)

T_{HS}	$\Sigma Q = 8(3.41) = 27.28$
150	28.49
145	25.11
147	26.45
148	27.13
148.2	27.26

T_J = 148.2 + 8 (2.15) (1.8) = 179.16 (81.75 °C)

Cost – 3 E103 HS – 3.65 $\left(\frac{2}{12}\right)$ (3) = 1.825

Box – & cover = 7.26
3 SC 250 (480 v) = 3 × 3.16 = 9.48

$18.57

(Have 33.25 °C margin)

b) Assume One H.S – E103 – 6" Long
SC 250 diode

ΣPd = 8 (3) (3.41) = 81.84

T_{HS}	ΣP_d (81.84)
140	56.29
150	73.36
155	82.22
154	80.43
154.5	81.32

$T_{HS} = 154.5°F$

$\therefore T_J = 154.5 + 8(2.15)(1.8) = 185.46$ (85.25°C)

Margin $= 115 - 85.25 = \underline{\underline{29.75°C}}$

$\therefore$ Use this option because the smaller heat sink is required and the margin are greater (T_J)

ie.

a) SC 245 - 3 reqd $= 3(2.94) =$ 8.82
Case & cover 7.26
HS - $3.65\left(\frac{7''}{12}\right) =$ 2.13
$\overline{18.21}$

T_J margin $= 100 - 87.85 = 12.15°C$

b) SC 250 - 3 reqd $- 3(3.16) =$ 9.48

Case & cover 7.26

Heatsink $- 3.65\left(\frac{6}{12}\right) =$ 1.83
$\overline{18.57}$ ✓

T_J margin $= 115 - 85.25 = \underline{\underline{29.75°C}}$ margin

Because of the mounting considerations - go to a 7" long HS. -

$\Sigma Pd = 8(3)(3.41) = 81.84$ - E103-7

T_{HS}	$\Sigma Q = 81.84$
140	64.40
145	74.02
150	83.89
147.5	78.93
148	79.91
149	81.90

$\therefore T_{HS} = 148°F$

$T_J = 149 + 8(2.15)(1.8) = 179.96°F$ (82.2°C)

$T_{margin} = 115 - 82.2 =$ 32.8°C margin

3 - SC 250 - 3(3.16) = 9.48
Cave (6 x 8 x 4) 7.26
1 - E103-7 3.65 (7/12) = 2.13
18.87

Assume 4" Long E103 section

(one diode per HS per Leg)

Pd / HS = 20 (3.41) = **68.2**

T_{HS}	ΣQ (68.2)	
140	39.59	
160	64.28	∴ T_{HS} = 163.2°F
162	66.88	
163	68.19	(which is only
163.2	68.4	marginally acceptable

Assume L = 4.5" Long, E103 section

T_{HS}	ΣQ (68.2)	
155	64.08	
157	66.89	∴ T_{HS} = 158°F
158	68.31	

$T_J = 158 + 20(2.15)(1.8)$

$= 235.4°F\ (113°C)$

Assume L = 5" Long - E103, one HS per Leg

T_{HS}	ΣQ (68.2)
150	62.6
✓ 152	65.6
153	67.15
153.5	67.9
153.75	68.2

$T_J = 154 + 20(2.15)(1.8)$

$= 231.4°F\ (110.8°C)$

∴ Total margin = 4.2°C + .11 (20) = 6.4°C

∴ @ R_{CHS} = .29 - T_J < 115°C by 6.4°C

@ L = 5" - 170 × 8 × 1 2 × 4 - 9.72 + 1.38 = 11.00"

HS = 2.65 (3) = 7.95", 3, -SC 250 (240) = 3 × 2.79 = 8.37 - Σ = 27."

b) Considering a E 360 section –

$L = 8''$, $P_1 = 9.7$, $P_2 = 32$

$F_n = .28$, $A_{fn}/in - 36.7$

T_{HS} max = 161.6°F

$\Sigma Pd = 25(3) = 60$ watts = 204.6

T_{HS}	$\Sigma Q = 204.6$
130	82.44
140	115.8
150	151
160	188
170	227
166	211
164.5	205

∴ $T_{HS} \doteq 164°F$

which is excessive

c) If Two diodes per line are used

$I_{rms}/\text{diode} = \frac{14.8}{2} = 7.2a$

use SC 245 T_J max = 100°C

Pd/diode = 8.3 watts $R_{J-C} = 1.80$ °C/w

T_{HS} max = $T_J - QER = 100°C - 8.3(1.8+.4)$

= 81.74°C (179°F)

Assume E360 HS 8" Long – are

$\Sigma HS\ pd = 8.3(6)(3.41) = 169.82$

T_{HS}	ΣQ
150	151.15
155	169.51

∴ $T_{HS} \doteq 155°F$

$T_J = 155 + 8.3(2.2)(\ldots$

$= 187°F\ (86°C)$

Cost Comparison —

1)

HS 3 - E103 - 5" Long - 3.65 $\left(\frac{5}{12}\right)(3)$ = 4.56

Box & Cover 8x12x4 = 9.72 + 1.38 = 11.10

Diodes - 3 - SC250 (240A) - 3x2.79 = 8.37

T_J = 110.8°C $24.03

2) 1 - E360 - 8" Long - 6.30 $\left(\frac{8}{12}\right)$ = 4.20

Box & Cover 8x8x4 = 7.48 + 1.10 = 8.58

Diodes - 6 - SC245 (240A) = 6x2.64 = 15.84

(one HS - 6 diodes) $28.62

d) Assume E360 HS 7" Long - (2 diodes/line) one HS

T_{HS}	ΣQ = 169.82
150	134
160	168.00
161	171.4
160.5	169.7

T_{HS} = 169.7°F

T_J = 169.7 + 8.3(2.2)(1.8)

= 202.6°F (94.7°C)

3) 1 - E360 - 7" Long 6.30 $\left(\frac{7}{12}\right)$ = 3.68

Box & cover - 8x8x4 8.58

Diodes - 6, SC245 6x2.64 = 15.84

(T_J = 94.7°C) $28.10

e) Assume E360 HS - L = 2.0" - Two diodes

per line - SC 245 - Pd/diode = 8.3 W

Pd/HS @ 2 diodes per HS = 16.6 (56.6

T_{HS}	ΣQ (W 6.6)
160°F	58.4
155°F	52.52
157	54.8
158	56.02

$T_{HS} = 158°F$

$T_J = 158 + \underline{8.5}(20)(\ldots$

$= 191.0°F\ (88.7°C)$

3 - E360 - 2" Long - $6.30 \times \frac{2}{12}(3) =$ \$3.15

Box - 6x8x4 & cover 7.26

Diodes - 6 SC245 $6(2.64) =$ $\underline{15.84}$

$T_J = \underline{88.7°C}$ $\underline{\underline{26.25}}$

[∴ The 3 - E103 heat sinks - one per each SC250 diode is the least costly arrangement -]

$Q = h_c A \Delta T$ $\Delta T = 154 - 100.0$
$= 54.0$

$$20(3.41) = h_c \left(\frac{(5)(20.063)}{144}\right)(54.0)$$

$$h_{c_{eff.}} = 1.813$$

$$m = \sqrt{\frac{hC}{kA}} = \sqrt{\frac{(1.813)(20.063)(144)}{(10)(90)(1.577)}} = 1.788$$

$$\theta_{x=L} = \frac{\theta_{x=0}}{\cosh mL} = \frac{54}{\cosh(1.788)\left(\frac{2.5}{12}\right)} = 50.4°F$$

∴ There is a 4°F drop down the fin –

f) Assume one diode ~~diode~~ per line – SD 260 isolated TO-3

$R_{J-C} = 1.55\ °C/watt$ –

$T_J\ max = 115°C$ $\quad I_{rms}/leg = 14.8a$

$P_d/leg\ per\ diode = 14.\ watts$

$T_{HS\,max} = T_J - \Sigma QR = 115 - 14(1.55 + .4)$
$= 87.7°C\ (189.86°F)$

Assume 8" Long E103 section (one HS)

$\Sigma P_d = 14.0(3)(3.41) = 143.22$

T_{HS}	$\Sigma Q = 143.22$
150	93.85
160	116.76
170	140.72
171	143.18

ORIGINAL PAGE IS OF POOR QUALITY

$T_J = 171°F + 14(1.95) \times 1.8 = 220.14°F\ (104°$
11°C margin

Assume 7" Long E103 section – one H.S.

T_{HS}	$\Sigma Q = 143.22$
170	125
180	147.5
175	136.3
[illegible]	143.02

$T_J = 178°F + 14(1.95)(1.8)$
$= 227.14°F\ (108°C$
7°C margin

7" Long E103, one HS - 3 - SC260 di...

1 E103 - 7" Long - $3.65\left(\frac{7}{12}\right)$ = $2.13

1 Box & Cover 6"x8"x4" - $7.26

Three SC 260 diodes 3.67 × 3 = 11.01

20.40

2) Assume 2" Long E103 section

3 Heat sinks, one SC260 diode per line -

$\Sigma P_d = 14(3.41) = 47.74$

T_{HS}	$\Sigma Q = 47.74$
150	28.49
160	35.50
170	42.83
173	45.09
174	45.85
176	47.37
176.5	47.76

$T_2 = 176.5 + 14(1.95)$ ...

$T_2 = 225.64$ (107.5 ...

∴ have a 7.5°C margin

3 E103 - 2" Long - $3.65 $\left(\frac{2}{12}\right)(3)$ = $1.82

1 Box & Cover 6"x8"x4" $7.26

Three SC260 diodes - $3.67 × 3 = 11.01

$20.09

To obtain even # of cuts in The extrusion - Assume $L = 6.75''$

T_{HS}	$\Sigma Q = 143.22$
179	141.35
180	143.55

$\therefore T_J = 180°F + 14(1.95)(1.8) = 229°F$
(109 °C)

$\therefore$ Margin = $\underline{\underline{6°C}}$

1 - E103 - 6.75 $= 3.65\left(\frac{6.75}{12}\right) = 2.053$

1 Box Cover $(6'' \times 8'' \times 4'')$ - 7.26

3 SC260 diodes - $3(3.67) = \underline{11.01}$

$\underline{\underline{\$20.32}}$

IV 10 HP - 440 volts -

I_{RMS}/leg = 13 amps

With an SC260 diode - Pd/diode = 12 watts

$R_{J-C} = 1.55°C/watt$

$\Sigma Pd = 12(3)(3.41) = 122.76$ BTU/hr.

E103 HS - 6.75" Long - 3 diodes per HS.

T_{HS}	$\Sigma Pd = 122.76$
160	101
165	111.4
170	121.91
171	124
170.5	122.9

$\therefore T_{HS} = 170.5°F$

$\therefore T_j = 170.5 + 12(1.95)(1.8) = 212.60°F$
$(100°C)$

V $\underline{10 HP - 240 volts}$

$I_{rms}/Leg = 25.9$ amps

Assume one SC265 diode per Leg - $P_d = 26.0$ watts per leg

& Assume one E103 - 6.75" HS per diode - $R_{J-C} = 1.10 °C/W$

$T_{HS\,max} = 115 - 26(1.10 + .4) = 76°C \; (168.8°F)$

$\Sigma P_d = 26(3.41) = 88.60$ BTU/hr

T_{HS}	$\Sigma Q = 88.60$
150	81.27
155	91.09
153	87.13
153.5	88.12
153.6	88.3
154	89.10

$\therefore T_{HS} \cong 154°F$

$T_J = 154 + 26(1.5)(1.8) = 224.2°F \; (106.7°C)$

$\therefore$ Three SC265 - $3 \times 4.24 =$ 12.72
Box Size $12 \times 15 \times 4$ - $14.86 + 232 =$ 17.18
HS - $\left(\frac{6.75}{12}\right)(3)(3.65) =$ 6.16
(36.06)

If Two diodes per Line are used - Irms / Leg = 25.9 amps

Irms / diode = 13 amps

Pd per diode = 10 watts

$T_{HS_{max}} = 115 - 10(1.10 + .4) = 100°C$ (210°F)

Assume Two heat sinks are used

Three diodes per H.S.

Pd / HS = 30 watts - E103-6.75

$\Sigma Pd/HS = 30(3.41) = 102.3$

THS	Σ Pd	E103-6.75
190	166.05	
150	81.28	
160	101.13	
162	105.23	∴ THS ≈ 160.5°F
161	103.2	
160.5	102.15	

$T_J = 160.5 + 10(1.5)(1.8) = 187.5°F$ (86.4°C)

(Need the 6.75" Length To mount all the components -

Cost -

6 - SC265 - 6(4.24) =		25.44
Box size 18" x 8" x 4 = 7.48 + 1.10 =		8.58
HS - $(3.65)\left(\frac{6.75}{12}\right)(2)$ =		4.11
		38.13

Assume E360 section –

one Heat sink for all diodes – Two diodes per Line –

From before – T_{HS} max = 212°F

$P_d/_{HS} = 6(10) = 60$ watts.

Assume L = 6.75"

$P_d = 60(3.41) = 204.6$

T_{HS}	ΣQ = 204.6
170	196.5
175	213.8
173	206.9
172	203.38
172.5	205.1
172.3	204.4

T_{HS} = 172.3 °F

$T_J = 172.3 + 10(1.5)(1.8) = 199.3$ (92.9°C)

Margin = 22.1°C

Cost –

6 – SC265 diodes – 6(4.24) = 25.44

Box size 8×8×4" – 8.58

Heat sink – $(6.30)\left(\frac{6.75}{12}\right)(1)$ = 3.54

\$37.56

VII 20 HP – 480 volts

Identical To the above

VII 20 HP - 240 volts

I_{rms}/Leg = 51.9 amps -

a) Assume 2 SC265 diodes per

Line - I_{rms}/diode $= \frac{51.9}{2} \doteq 26$ amps

Pd/diode = 26 watts.

Assume 6 diodes on the Heat sink

E360 section - 6.25" Long -

$\Sigma Pd = 6(26)(3.41) = 531.96$

T_{HS} max $= 115 - 1.5(26) = 76°C$ (168.8°F)

THS	ΣQ = 531.96
150	130.71
200	305.5

THS > 200°F

∴ The heat sink Temperature is excessive -

b) Assume 2 diodes per line

3 heat sinks - each E360 section

2" Long -

$\Sigma Pd = 26(2)(3.41) = 177.32$

THS	ΣQ = 177.32
150	46.79
180	83.11
200	109

∴ THS > 200°F

and is not

acc... [illegible]

c) Assume 3" Long section - 2 D/Line

$\Sigma P_d = 177.32$

T_{HS}	$\Sigma Q = 177.32$
150	65.7
170	98.98

d) Assume 6.75" Long section - 2 D/Line
one HS/Line

T_{HS}	$\Sigma Q = 177.32$
150	130.72
160	162.87
165	179.57
164	176.15

$\therefore T_{HS} = 165°F$

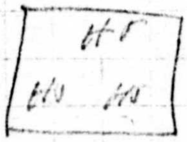
$T_J = 165 + 26(1.5)(1.8) = 235.2°F\ (113°C)$

2°C margin —

Cost —

6 SC265 diodes — $4.24 \times 6 =$ 25.44

HS — $\frac{6.75}{12}(6.30)(3) =$ 10.63

Box 

$15" \times 15" \times 4" = 17.46 + 2.68 =$ 20.14

56.21

e) Assume $12 \times 8 \times 4$ Box

All diodes on one HS. - E 360 - 12" Long

$\Sigma pd = 26(6)(3.41) = 531.96$

THS	$\Sigma Q = 531.96$
150	214.14
180	378
200	499

THS > 200°F and is not acceptable

f) Assume - 12 X 15 X 4" Box

E360 - 15" Long E360 section

$\Sigma Pd = 531.96$

THS	$\Sigma Q = 531.96$
150	259.68
170	389.75
180	459
200	605
190	531

THS ≅ 190°F and is not acceptable

g) Assume 12X18X4" Box

E360 - 18" Long - 2d/Line

THS	$\Sigma Q = 531.96$
150	304.16
160	378
180	537
175	496
179	529

∴ THS ≅ 180°F and is still unacceptable

h) Assume a 18" X 24 X 6" Box

E360 - 24 - 2d/Line

$\Sigma Pd = 531.96$

T_{HS}	$\Sigma Q = 531.96$	
150	390.76	
160	486.17	$\therefore T_{HS} \cong 165°F$
165	535	
164	525	

Cost - 6 SC265 diode $= 4.24 \times 6 = 25.44$

$HS = 6.30 \left(\frac{24}{12}\right)(1) = 12.60$

Box + blower $42.94 + 4.60 = 47.54$

$\underline{\underline{85.58}}$

d) Assume $\underline{3}$ diodes per line

$I_{rms}/\text{diode} = \frac{51.9}{3} = 17.3$ amps

$Pd/\text{diode} = 15$ watts

$T_{HS\,max} = 115 - Q\Sigma R = 115 - 15(1.5) = 92.5°C$
(198.5°F)

Assume all diodes on one heat sink E360 - 8" Long.

$Pd/HS = 15(9)(3.41) = 460.35$

T_{HS}	$\Sigma Pd = 460.35$	
150	151.14	
180	267.58	$\therefore T_{HS} > 200°F$
200	353	

and is unacceptable

(Ok)

a) Assume 3 diodes per line

Irms/diode = 17.3 amps   Pd/diode = 18

10" Long E360 section

THS	$\Sigma Pd = 460.35$
180	323
190	374
200	427
220	538
210	481
208	470
207	465

$\therefore$ THS > 200°F

and is unacceptable

b) Assume 3 diodes per Line

Pd/diode = 15 watts

12" Long E360 section

THS	$\Sigma Pd = 460.35$
180	378
185	408
187	420
190	438
195	468

$\therefore$ THS ≅ 195°F

$T_J = 195 + 15(1.5)(1.8) = 235.5°F$ (113°C)

(2°C margin)

Cost - 9 - S6265 diodes - 9 × 4.24 = 38.16

HS - 6.30 $\left(\frac{12}{12}\right)$ = 6.30

Box 10×12×4 - 11.14 + 1.72 = 12.86

$57.32

2) Trying 3 diodes Line - each Line with its own heat sink

T_{HS} max = 198.5°C

Pd/HS = 15 (3) (3.41) = 153.45

E 360 section - 4" Long

T_{HS}	$\Sigma Q = 153.45$
150	83.8
160	104.5
170	126
180	148
190	171
182	153.20

∴ T_{HS} = 182 °F

T_J = 182 + 15 (1.5) (1.8) = 222.5°F (105.8°C)

115 - 105.8 = 4.2°C margin

Cost - 9 × $4.24 - diodes = 38.16

HS - $6.30 $\left(\frac{4}{12}\right)$ (3) = 6.30

Box - 12 × 15 × 4 $14.86 + 2.32 = 17.18

$61.64

m) Assume 4 diodes per line

I_{rms}/diode = $\frac{51.9}{4}$ = 13 amps

Pd/diode = 10 watts

Assume one heat sink - L = 10"

Pd/HS = 12(10)(3.41) = 409.2

THSmax = 115 - QΣR

T(HSmax) = 115 - 10(1.5) = 100°C = 212°F

THS	ΣQ = 409.2
180	323.86
190	374.68
200	427
196.7	409.25

T_J = 196.7 + 10(1.5)(1.8) = 223.7 (106.2°C)

Margin = 115 - 106.2 = 8.8°C

Cost -

12 × 4.24 = diode cost = 50.88

Heat sink - 6.30 $\left(\frac{10}{12}\right)$(1) = 5.25

Box - 8" × 10" × 4" = 8.58 + 1.22 = 9.80

$65.93

N) Considering Section E288

Cost per foot — estimated as

$\frac{3.65}{1.517} = \$2.406/\text{ft-in}^2$ (E103)

$\frac{6.30}{2.28} = \$2.76/\text{ft-in}^2$ (E360)

$\therefore \frac{4.608}{2.27} \times \$2.76 = \$12.72$ per foot

$P_{n=1.0} = 9.875 + 1.32(2) = \underline{12.52}$

$P_{n=N} = 1.0\ (46) = \underline{46}$

$A_{fin/fin} = 65.7 - 9.875 = \underline{55.825}$

$W = 1.0 \quad D = .25 \quad L = 6.75$

$R_2 = W/D = \frac{1.0}{.25} = 4.0, \quad R_1 = \frac{L}{D} = \frac{6.75}{.25} = 27$

$F_{1-2} = .78 \qquad F_A = 1.0 - .78 = .22$

If $L = 2''$ $\quad R_1 = \frac{L}{D} = \frac{2}{.25} = 8$

$F_{1-2 \atop L=2} = .7 = \quad F_A = 1 - .7 = .3$

$F_{A \atop L=2} = \underline{.3}, \quad F_{A \atop L=6.75} = \underline{.22}$

Assume Two diodes per line per HS

SC26T THS max = 168.8°F

$Pd/_{1\text{-}HS} = 54\ (3.41) = 184.14$

$L = 2.0''$

cont. on page 66

T_{HS} $\Sigma Q = 177.72$

150	69.42	
180	120	$\therefore T_{HS} > 168$ and is unacceptable

Assume $L = 4''$ $F_N = .26$

T_{HS}	$\Sigma Q = 177.72$	
170	181.94	
168	175.6	$\therefore T_{HS} = 168.5$
168.5	177.18	and is marginally acceptable -

Cost 6-SC265 = 6 × 4.24 = 25.44

HS - (E288) $\overset{8}{12.72}\left(\frac{4}{12}\right)(3)$ = 12.72

Box - 12" × 15" × 4 = 14.46 + 2.72 = 17.18

$\overline{\overline{55.34}}$

VIII 30 HP - 480 volts

I_{rms} / Leg = 77.8/2 = 38.9 amps

If one diode per Leg is used -

SC 265 P_d = 44 watts

$T_{HS}\,max$ = 115 - 44 (1.5) = 49°C (120°F)

which is very low -

a) Consider 2 diodes per leg

$\underline{I_{rms}/\text{diode}} = 195$ amps

$Pd/\text{diode} = 18$ watts

$T_{HS\,max} = T_J - Q\Sigma R = 115 - 18(1.5) = 88°C$
(190.4°F)

Assume E360 section 12" Long
(one heat sink) - 6 diodes

$Pd/HS = 18(6)(3.41) = 368.28$

$\underline{T_{HS}}$	$\underline{\Sigma Q = 368.28}$	
180	378.74	
175	349	
177	361	$\therefore T_{HS} \doteq 178°F$
178	367	
178.5	370	

$T_J = 178 + 18(1.5)(1.8) = 226.6°F\,(108°C)$

Margin = $\underline{7°C}$

Cost - 6-SC265A40-6(5.14) = \$30.84

HS - $\dfrac{12''}{12}(6.30)$ = 6.30

Box - 8" × 12" × 4" - 9.72 + 1.38 = $\underline{11.10}$
\$48.24

b) Assume 2 diodes per line
and one H.S. 10" Long -

T_{HS}	$\Sigma P_d = 368.28$
180	323.86
185	349.03
190	374

∴ The heat sink is marginal - less scrappage with 12" Length

c) Assume three heat sinks -

Two diodes per H.S. -

$P_d/HS = 36 (3.41) = 122.76$ $L = 4"$

T_{HS}	$\Sigma P_d = 122.76$
170	126.10
169	123.4
168.5	122.8

∴ $T_{HS} = 168.5$

$T_J = 168.5 + 18(1.5)(1.8) = 217.1°F (102.8°$

Margin = $\underline{12°C}$

IX 30 HP - 240 volts -

I_{rms} per Leg = 77.8 amps -

Assume 4 diodes per Leg

I_{rms}/diode $= \dfrac{77.8}{4} = 19.45$ amps

P_d/diode = 18 watts.

THS max = 190.4°F

Assume Two Heat sinks - ea 12" Long E360 section (12 diodes Total)

i.e. 6 diodes per HS -

Pd/HS = 6 (18) (3.41) = 368.28

THS	ΣQ = 368.28
178.5	370.00

∴ THS ≅ 178.5°F

$T_J = 178.5 + 18 (1.5) (1.8) = 227°F (108°C)$

X 40 HP - 480 volts -

$$I_{rms}/Leg = \frac{H.P. (746)}{1.73\ V_{rms}\ (eff.) (P.F)}$$

$$= \frac{40\ (746)}{(1.73)(480)(.8)(.866)} = 51.9 \text{ amps}$$

(same as 20HP - 240 volts)

XI 40 HP - 240 volts

$I_{rms}/Leg = 51.9 (2) = 103.8$ amps

c) Assume 6 diodes/Line

$$I_{rms}/diode = \frac{103.8}{6} = 17.3 \text{ amps}$$

C-4

Pd / diode = 15 watts ea

T_{HS} max = T_j − QΣR = 115 − 15(1.5) = 92.5°C
(198.5°F max)

6 × 3 = 18 diodes Req'd –

Assume 9 diodes per HS –

Pd/HS = 9(15)(3.41) = 460.35

Assume L = 15" Long

T_{HS}	ΣQ = 460.35
180	459.03
180.3	461.15

∴ T_{HS} = 180.2°F

T_j = 180.2 + 15(1.5)(1.8) = 220.7°F (104.8°C)

Cost –

Diodes – 18 SC265 = 18(4.24) = $76.32

HS – $6.30 (15/12)(2) = $15.75

Box 15 × 15 × 4 & cover – 17.46 + 2.68 = $20.14

$112.21

Checking the previous calculations

I) 5 HP 480 volts

I rms / Leg – 7.2 amps.

Using one SC250 diode per Leg

I rms / diode = 7.2 amps.

Pd / diode = 8 watts –

R_{J-C} = 1.75 °C/watt

$T_{HS\,max}$ = 115 – QΣR = 115 – 8(1.75+.4)

= 97.8°C (208.04°F)

[Using one E103 heat sink for all diodes – Pd / heatsink = 8(3)(3.41)

= 81.84 BTU/hr.]

L = 6.75"

THS	ΣQ = 81.84
148	77.51
149	79.44
150	81.37

∴ THS = 150°F

T_J = 150 + 8(1.75+.4)(1.8) = 180.96°F (82.7

Margin = 115 – 82.7 = 32.3°C

II 5 HP 240 volts

I_{rms}/Leg = 14.8 amps

Using one SC260 diode per Leg

I_{rms}/diode = 14.8, Pd/diode = 14 w/Leg

R_{J-C} = 1.55 °c/w

T_{HS} max = T_J - QΣR = 115 - 14 (1.55 + .4)

= 87.7 °c (189.86 °F)

Using one E103 HS - 6.75" Long for

all The diodes -

Pd/HS = 14 (3)(3.41) = 143.22 BTu/hr.

T_{HS}	ΣQ = 143.22
179	141.51
180	143.71

∴ T_{HS} = 180 °F

T_J = 180 + 14 (1.95)(1.8) = 229.14 °F (109.5°

Margin = 115 - 109.5 = 5.5 °c

III 10 HP - 480 volts

Same as The above - except.

I_{rms} = 25.9/2 = 13 amps per Leg

Pd = 12 watts/diode (SC260)

Pd/HS = 12(3)(3.41) = 122.76 - T_{HS} = 170.5

T_J = 170.5 + 12 (1.95)(1.8) = 212.62 °F (100 °C)

IV. 10 HP - 240 volts

I_{rms} / Leg = 25.9 amps

Using 2-SC265 diodes per Line

I_{rms} / diode = 13 amps

Pd / diode = 10 watts

R_{J-C} = 1.10 °C/watt

$T_{HS\,max} = T_J - Q\Sigma R = 115 - 10(1.10 + .4)$

$= 100\,°C\ (212\,°F)$

Using one E360-6.75 section for all the diodes (3)

Pd / heat sink $= 6(10)(3.41) = 204.6\ \frac{Btu}{hr.}$

THS	$\Sigma Q = 204.6$
172	203.389
172.3	204.42

$\therefore T_{HS} = 172.3\,°F$

$T_J = 172.3 + 10(1.5)(1.8) = 199.3\,°F\ (92.9\,°C$

Margin $= 115 - 92.9 = \underline{\underline{22.05\,°C}}$

Considering The use of a 6" heat sink - (was 6.75")

I - 1 HP 240V & 480 volt - no heat sink Required

II a) 5 HP - 480 volt - open -

b) 5 HP - 240 volt - I_{rms} leg = 14.8a

Pd / diode / leg = 14 watts

Pd per heat sink @ 3 diodes per heat sink = 42 watts.

Considering an E133 section -

$\Sigma Pd = 42(3.41) = 143.22$

@ L = 6.75 $T_{HS} = 180°F$ pd = 143.77

@ L = 6.00

T_{HS}	Pd
185	139.82
186	141.86
187	143.90

$\therefore T_{HS} = 187°F$

$T_J = T_{HS} + \Sigma QR = 187°F + 14(1.55 + .4)(1.8)$

$= 236.14°F\ (113.4°C)$ which is acceptable

(2)

III 30 HP - 240 Volts -

I_{RMS} = 77.8 watts per Leg

a) Require $240\sqrt{2}$ = 339 min

Vdrom voltage -

Consider one T 8420 D (80A)

R_{J-C} = .4 °C/watt

T_J max = 110 °C R_{C-HS} = .28 °C/W (see below)

EE package 1/2-20 stud. - 1.055 HEX

Contact area - .66 in²

@ $k = 30 \frac{BTU-in}{HR-ft^2-°F}$ t = .020 in THK

A = .66 in²

$$R = \frac{L}{kA} = \frac{.020\,(144)\,(3.41)}{30\,(.66)\,(1.8)} = .28 \text{ °C/watt}$$

$P = EI$ = 77.8 (1.5v) = 116.7 watts

∴ $T_{HS}(max) = T_J - \Sigma QR$

= 110°C - 116.7 (.4 + .28) = 30.64 °C
(87.2°F)

~~Considering an E103 heat sink~~

~~with L = 6.0"~~

b) Consider Two T6420D (40A)
in parallel -

I_{rms} / diode = 77.8/2 = 38.9 amps

Power / diode = EI = (1.5)(38.9) = 58.35 watts

Package Type - D-1 - 1/4-28 stud
with .554 HEX

R_{J-C} = 1.0 °C/watt

T_J max = 110°C

$K_{Al_2O_3} = \frac{30\ BTU}{hr\,ft^2\,°F}$ /in

$A_C = .18\ in^2$

$$R_{CHS} = \frac{L}{KA} = \frac{.020(144)(3.41)}{(30)(.18)(1.8)} = 1.01\ °C/w$$

$\therefore T_{HS_{max}} = T_J - Q\Sigma R = 110 - 58.35(1.0 + 1.01)$
$= \underline{-7.28°C}$ max

c) Consider Two T8420D diodes
per Leg - Pd/diode = 58.35 watts

R_{J-C} = .4 °C/watt - R_{C-HS} = .28 °C/w

$T_{HS_{max}}$ = 110°C - 58.35(.4 + .28) = 70.32°C
(158.6°F)

Considering as E360 H.S.

Two diodes per HS - $P_d/HS = 58.35 \times 2 = 116.7\,W$

$L = 6.0''$

T_{HS}	$P_d = 397.95$
158.6	143.18
200	276
250	463
245	443
225	367
230	385
232	393
233	396
234	400

$\therefore T_{HS} = 233.5\,°F$

$T_J = 233.5 + 58.35(.68)(1.8) = 304.9\,°F\,(151\,°C)$

Considering as E613 H.S.

One diode per H.S.

$P_d/HS = 58.35$ watts

for 3'' Long H.S. - $R_{HS-c} = 1.1\,°C/W$

$\Delta T = QR = 58.75(1.1) = 64.63\,°C$

$T_{HS} = 100\,°F + 64.63(1.8) = 216.33\,°F$

30 HP - 480 volts

Considering - I_{RMS}/Leg = 38.9 amps

Pd/Leg = EI = 1.5 (38.9) = 58.35 watts

Consider Two diodes per Leg

T 6420 N (5=1) Isolated case -

R_{J-C} = 1.0 °C/watt R_{C-HS} = 1.01 °C max

Pd/diode = 58.35/2 = 29.18 watts

$T_{HS\,max} = T_J - \Sigma QR = 110°C - 29.18 (1.0 + 1.01)$
= 51.35 °C (124.4 °F)

Considering an E 360 HS

Pd/HS = 29.18 (2) = 58.36 watts.

L = 6.0"   Pd = 199.008

T_{HS}	ΣPd = 199.01
124	49.5
200	276
175	193
177	199.8

∴ T_J = 177°F + 29.18 (2.01)(1.8) = 283 °F (139.5°

If L = 8.0"

THS — $\Sigma Pd = 199.01$

THS	ΣPd
150	151
160	188
165	207
162	195
163	199.7

$T_J = 163 + 29.18(2.02)(1.8) = 269°F\ (131.7°C)$

Considering an E 288 H.S.

$L = 4.00''$

THS — $\Sigma Pd = 199$

THS	ΣPd
150	117.6
200	275
175	192

$L = 8.00$

THS — $\Sigma Pd = 199$

THS	ΣPd
150	210
145	185
148	200

$T_J = 148 + 29.18(2.02)(1.8) = 254°F\ (123°C)$

ORIGINAL PAGE IS
OF POOR QUALITY

Considering 1.0 HP - 480 volt.

T 6420 N $R_{J-C} = 1.0$, $R_{C-HS} = 1.01$

$I_{RMS}/Leg = 25.9/2 = 13$ amps

$P_d/Leg = EI = 13(1.5) = 19.5$ watts

T_{HS} max $= T_J - \Sigma QR = 110 - 19.5(2.01)$

$= 70.81°C\ (159.45°F)$

Considering an E 103 H.S.

L = 6.0 inches - one diode per Leg.

T_{HS} $\Sigma P_d = 19.5(3.41) = 66.495$

140	56.36
145	64.79
147	68.22
146	66.5

$\therefore T_{HS} = 146°F$

$T_J = 146°F + 19.5(2.01)(1.8) = 216.55°F$ $(102°C)$

$\therefore$ The configuration is acceptable.

$Q = K m A \theta_0 \tanh mL$

$T_{x=L} - T_f = \dfrac{T_{x=0} - T_f}{\cosh mL}$

$Q = h_T A \Delta T$

$h_T = \dfrac{Q}{A \Delta T} = \dfrac{19.5(3.41)(14\ldots}{(2)(20.063)(3)\ldots}$

$h_T = 1.729$ BTU

$$m = \sqrt{\frac{hC}{kA}} = \sqrt{\frac{1.729\,(20.063)(144)}{12\,(110)(1.517)}}$$

$$m = 1.579$$

$$T_{x=L} = T_f + \frac{T_{x=0} - T_f}{\cosh mL}$$

$$T_{x=L} = 100\,°F + \frac{146 - 100}{\cosh\left(1.579 \times \frac{3}{12}\right)} = 142.63\,°F$$

∴ The drop down the fin is only 3.5 °F

Considering $\underline{20 HP}$ - $\underline{480 volt}$

T6420N $R_{J-C} = 1.0$, $R_{C-HS} = 1.01$

$I_{Rms}/Leg = \frac{51.9}{2} = 25.95$ amps.

$Pd/Leg = 25.95(1.5) = 38.93$ watts
@ Two diodes per Leg

$T_{HS} max = T_J - \sum QR = 110 - \frac{38.93}{2}(1.0 + 1.01)$

$T_{HS} max = 70.87°C$ ($\underline{159.58°F}$)

Assume 2 diodes per heat sink - E103 Type $L = 6''$

$\underline{T_{HS}}$	$\underline{\sum Pd} = 38.93(3.41) = 132.75$
140	56.36
175	119.86
190	150
185	139

$\therefore T_{HS} \approx 185°F$ which is excessive

Assume $\underline{2}$ diodes per heat sink

✓ $\underline{E360}$ Type $\underline{L = 6''}$ - Box size 13"x15"x4"

$\underline{T_{HS}}$	$\underline{\sum Pd}$ = 132.75 BTU/hr
140°F	90.54
145	104.19
150	118.2
160	147.33
155	132.6

$\therefore T_{HS} = 155°F$

$T_J = 155 + \frac{38.93}{2}(2.01)(1.8) = 225.42°F$ ($\underline{107°C}$)

Considering the 30HP – 240 VOLT
Condition Again

a) 2 diodes per Line

I_{rms}/Line = 77.8 amps –

I_{rms}/diode = $\frac{77.8}{2}$ = 38.9 amps

Considering an SC265 – 42 watts/diode

R_{J-C} = 1.10 °C/W R_{C-HS} = .4°C/W

T_J max = 115°C

T_{HS}max = T_J – QΣR = 115 – 42(1.1+.4) = 52°C
= 125.6°F
using 2 SC265 (Low H.S. Temp
Reqmts)

Pd/HS – 42×2 = 84 watts = 286.41 BTU/hr.

Assume E288 H.S. L = 6.0"

T_{HS}	ΣPd 286.41
110	24.7
150	165
175	270
180	293

T_{HS} ≅ 179 °F
which is excessive –

If indium foil is used
R_{C-HS} = .1°C/W

T_{HS}max = T_J – QΣR = 115 – 42(1.1+.1) = 64.6°C
(148°F)

which is still Too Low -

If each diode has a E133

Type heat sink - L=6"

Pd = 42(3.41) = 143.22 BTU/hr

THS	ΣPd	143.22
120	25.17	
150	73.44	
160	91.44	∴ THS = 187°F
180	129	
185	139	which is excessive
187	143	even with indium foil

∴ 2 diodes per line max of the

SC265 Type are out —

Consider T8400 D (EE - isolated case)

$R_{J-C} = .4\,°C/watt \quad R_{CHS} = .28\,°C/W$

Assume Two diodes per line -

$I_{RMS}/Leg = 77.8$ amps

$I_{RMS}/diode = \frac{77.8}{2} = 38.9$ amps

$Pd/diode = EI = 1.5(38.9) = 58.35$

$T_{HS\,max} = 110 - 58.35(.4 + .28) = 70.32\,°C$
$(158.6\,°F)$

Pd/HS @ one diode per HS $= 58.35(3.41) = 198.9$

if $L = 9''$ E103 section is assumed

T_{HS}	$\Sigma Pd = 158.53$
140	80.34
160	130.14
165	143
185	198

$\therefore T_{HS} = \underline{185°F}$

From IERC chart

$R_{L=9''} = .6\,(R_{\frac{L}{2}=3''}) = .6(1.8) = 1.08\,°C/W$

$\therefore T_{HS} = 100 + (58.35)(1.08)(1.8) = 213°F$

which is excessive —

E613 Type HS 6" Long –

$R_{L=6''} = .7(1.1) = .77\,°C/W$

$T_{HS} = 100 + 58.35(.77)(1.8) = 180\,°F$

$\therefore$ E613 Type HS – 9" Long

$R_{L=9} = .6(1.1) = .66\,°C/W$

$T_{HS} = 100 + 58.35(.66)(1.8) = 169.3\,°F$

E613 Type HS 12" Long one diode / HS.

$R_{L=12} = .53(1.1) = .583$

$T_{HS} = 100 + 58.35(.583)(1.8) = \underline{\underline{161.23\,°F}}$

✓ $\therefore$ would need a E613 HS – 9" Long

one T8420D diode per HS – Two diodes

- If use E615 Type H.S.

$R_{L=3"} = .81\,^\circ C/W$

6" Long -

$R_{^\circ C/W\; L=6} = .7(.81) = .57\,^\circ C/W$

$T_{HS} = 100^\circ F + 58.35(.57)(1.8) = \underline{159.86^\circ F}$

∴ Could use Two diodes (T8420D) per Line of one H.S per diode Type E615 - 6" Long

Total heat sinks Req'd - 12

If one used E615 Type HS $\underline{L = 12"}$

$R_{L=3"} = .81\,^\circ C/W$

Consider Two diodes per heat sink

Total power per H.S = $58.35 \times 2 = 116.7$ watts

a) From IERC -

$R_{L=3"} = .81\,^\circ C/watt$

$R_{L=12} = .53(.81)\,^\circ C/W = .43\,^\circ C/W$

Using the 70% reduction factor -

$R_{L=12"} = .43 \times 7 = .301\,^\circ C/W$

$T_{HS} = 100^\circ F + 116.7(.301)(1.8) = \underline{163.2^\circ F}$

b) Using Aham data –

12" Long – Two devices per H.S.

Area per device = $71.4 \,(6) = 428.4 \text{ in}^2$ (in^2/in)

$R_{\theta CA/W} = .57\,°C/W \times .7 = .399\,°C/W$

$\Sigma R_{\theta CA/W} = \frac{.399}{2} = .2\,°C/W$

$T_{HS} = 100°F + 116.7(.2)(1.8) = \underline{142\,°F}$

c) Using the "formula"

T_{HS}	$\Sigma P_d = 116.7(3.41) = 397.9$	
130	240	
155	491.56	
150	438	$\therefore T_{HS} \approx 147\,°F$
145	386	
147	407	which agrees with
146	397	the above results.

Used. $L = 12"$, $T_f = 100°F$, $P_1 = 1.562$

$P_2 = 65"/\text{in}$ $F_N = .6$, $A_f/\text{in} = 71.4 \text{ in}^2/\text{in}$
(EG15 section)

$T_{HS} = 147 + 58.4(.4 + .28)(1.8) = 218.5°F\,(104°C)$

Considering the 30 HP – 440 volt condition

$I_{RMS}/\text{Leg} - 77.8/2 = 38.9$ amps

Assume two T642.. diodes in parallel –

$R_{J-C} = 1.0°C/W$, $R_{C-HS} = 1.01°C/W$

$Pd/\text{diode} = \frac{38.9}{2}(1.5) = 29.18$ watts

$T_{HS} = 110°C - 29.18(1.0 + 1.01) = 51.35°C$
(124°F)

If Two diodes per HS are used—

Assume L = 12" EG15 section

$Pd/HS = 2(29.18)(3.41) = 199.00$

T_{HS}	$\Sigma Pd = 199.00$
110	68.3
115	108.12
120	150.25
125	194
126	203
125.5	198.85

∴ $T_{HS} = 126°F$

and is very close To being acceptable

5HP 480 volt - Condition

$I_{rms}/leg = \frac{14.8a}{2} = 7.4$ amps.

$Pd/Leg = 7.4(1.5) = 11.1$ watts.

Assuming T 6420N diode, one per leg

$R_{J-C} = 1.0\,°C/W$ $R_{CHS} = 1.01\,°C/W$

$T_{HS\,max} = T_J - Q\Sigma R = 110 - 11.1(1.01+1.0)$

$= 87.69°C\ (189.8°F)$

Assume Three diodes on one

E103 Type HS, L=6"

$Pd = 11.1(3)(3.41) = 113.55$

T_{HS}	$\Sigma Pd = 113.55$	
150	73.44	
160	91.40	
170	110.18	$\therefore T_{HS} = 172°F$
175	119.86	
172	114.0	and is acceptable -

$T_J = 172°F + 11.1(2.01)(1.8) =$

10 HP - 240V - 6" Long E360 HS

$\Sigma Pd = 60 \times 3.41 = 204.6$

T_{HS}	$\Sigma Pd = 204.6$
170°F	177.76
175	193.44
177	199
178.5	204.6

$\therefore T_{HS} = 178.5°F$

[6 diodes/HS]

$T_J = T_{HS} + Q\theta R = 178.5 + 10_w(1.10 + .4)(1.8)$

$= 205.5\ °F\ (96.3°C)$

20 HP - 240 VOLT

E360 section - 6" Long

Two diodes per HS.

$\Sigma Pd = 54\ (3.41) = 184.14$ BTU/hr

T_{HS}	ΣPd
150	118
160	147.34
165	162.39
170	177.76
177	199
175	193
172	184

$\therefore T_{HS} = 172°F$

$T_J = T_{HS} + Q\theta R = 172°F + 26(1.10 + .4)(1.8)$

$= 242.2\ °F\ (116.7°F)$

which is a bit high

Looking at The 10 HP-480 volt Case again -

Assume E360 HS - L=10"

3 diodes per heat sink

$T_{HS}\ max = T_J - QER = 110°C - 19.5_{W}(2.01)$

$= 159.45°F$

$\Sigma Pd/HS = 3(19.5)(3.41) = 199.45$

T_{HS}	$\Sigma Pd = 199.45$	
140	140.29	
150	183.04	
152	191.85	$\therefore T_{HS} = 153.5°F$
153	196.3	
153.4	198.	

$T_J = T_{HS} + QER = 153.5 + 19.5(2.01)(1.8)$

$= 224.05°F\ (106.7°C)$

Looking at The 20 HP 480V unit again -

If one assumes Three diodes per heat sink of The E360 Type

Pd/diode = 19.5 watts

THS max = 159.58°F (REF pg 81)

$\Sigma Pd = 19.5(3) = 58.5_W = 199.45 \frac{BTU}{hr}$

∴ Could use the same configuration as the 10_{HP}, 480V but would need 2 heat sinks 10" Long

---

Looking at the 20HP 240 volts unit again

26 watts = Pd/diode –

If consider 3 diodes per HS.

$\Sigma Pd / HS = 3(26) = 78_W = \underline{265.98}$

THS max = TJ – QΣR

= 115°C – 26(1.10 + .4) = 76°C (168.9°F)

Assume an E360 section – L=10"

THS	ΣPd = 265.98
160	227.9
165	251.2
167	260.6
170	274

∴ THS = 168°F

$$T_J = T_{HS} + Q\,\varepsilon R = 168^\circ F + 26\,(1.5)(1.8)$$
$$= 238.2\ ^\circ F\ (114.5^\circ C)$$

APPENDIX K

THERMAL ANALYSIS, 3Ø CONTROLLERS, 150°F

Thermal Analysis for Iveco Controllers

$$I_{rms} = \frac{H.P. (746)}{(1.73)(V_{rms})(\text{efficiency})(P.F)}$$

Power/diode = EI (% duty cycle)

Assume that from 10-30 HP, efficiency = .8; & 1-5 HP, eff. = .7

P.f. = .866 in all cases -

E = 2 volts

$$I_{rms_{30HP}} = \frac{30(746)}{(1.73)(240)(.8)(.866)} = 77.8a$$

$$\text{Power/diode} = \underset{V}{(2)}\underset{I}{(77.8)} = 155.6 \text{ watts}$$

(100% duty cycle)

Total power dissipation on the heat sinks = 466.8 watts.

HP (230V)	(240V) I_{RMS} per Leg (amps)	(240V) Pd Watts/Leg	(240V) ΣPd (watts)
30	77.8	155.6	466.8
20	51.9	103.7	311.2
10	25.9	51.8	155.61
5	14.8	29.6	88.9
1	2.96	5.93	17.8

HP	Triac #	Stud size	Foot print	R_{j-c} °c/w
30	T8410 (DD)	1/2-20	1.0" DIA	.35
20	T8411 (DD)	1/2-20	"	.35
10	T6420 (J-1)	1/4-28	.54" DIA	1.0
5	T6411 (H-1)	1/4-28	.54" DIA	.9
1	2N5574 (H)	1/4-28	.54 DIA	1.0

Determining the maximum heat sink Temperature in all of the above cases –

Assume $T_{junction}$ = 150°C max –

(B)

a) 30 HP Case

Assume 1/2"-20 Stud is Torqued To 125 in-lb min & That silicone grease and a .002" THK mica washer is used at the interface

Contact area $= \frac{\pi}{4}\left[d_f^2 - d_s^2\right]$

$= \frac{\pi}{4}\left[1.0^2 - .5^2\right] = .589 \text{ in}^2$

$K_{mica} = .34 \frac{BTU}{hr\text{-}ft^2\text{-}°F/ft}$ (.002" THK)

$K_{silicone\ grease} = .45 \frac{BTU}{hr\text{-}ft^2\text{-}°F/ft}$ (.001" THK)

$\Sigma R_{contact} = R_{mica} + R_{silicone\ grease}$

$= \frac{.002\,(144)\,(3.41)}{(12)\,(.34)\,(.59)\,(1.8)} + 2\left[\frac{.001\,(144)\,(3.4}{(.45)\,(12)\,(.59)\,(1.}\right.$

$R_{contact} = .23 + .17 = .40$ °C/watt

ΔT (junction To case) $= QR = 155.6\,(.35) = 54.5°C$

$\therefore T_{(heat\ sink,\ max)} = 150°C - 54.5°C - .40\,(155.6)$

$= 33.26°C$

The 33.26°C heat sink Temperature (maximum) is less Than The maximum inlet air Temperature of 140°F (60°C) Therefore Two diodes will be Required in parallel in each Leg.

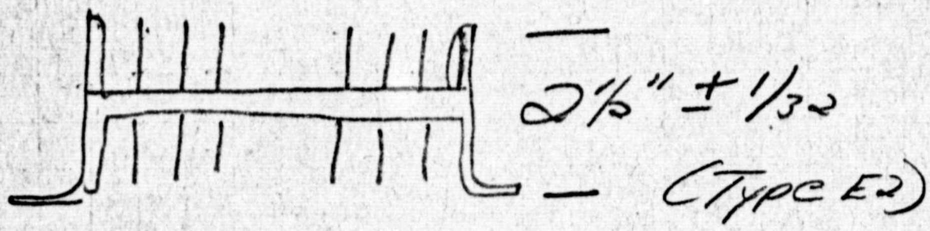
$$\therefore T_{\substack{\text{Heat sink}\\ \text{(max.)}}} = 150°C - Q\Sigma R$$

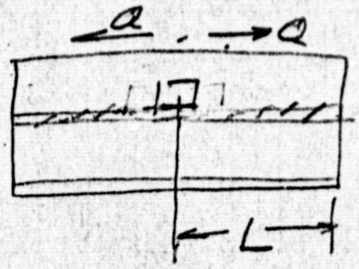
$$= 150 - \frac{155.6}{2}\left[.35 + .40\right]$$

$$= 91.65°C \ (196.9°F)$$

$T_{air} = 140°F = 60°C$ (max.)

Considering an IERC style heat exchanger - Type E2





Cross sectional area =

$$.185\left[4.5 - 2(.43)\right] + (2.5 - .185)(.090)(8)$$

$$= 2.34 \text{ in}^2$$

Weight per foot length $= (2.34)(12)(.1)$

$= 2.80$ lbs/foot

The perimeter of the section is -

$$\left[4.5 - 2(.43)\right](2) + (2.5 - .185)(16) = 44 \text{ in.}$$

(1) $Q = K\, m\, A\, \theta_0 \tanh mL$

$Q = \text{power} = \frac{155.6}{4}(3.41) = 132.65 \frac{\text{BTU}}{\text{hr.}}$

$m = \sqrt{\frac{hC}{KA}}$

h = film coef. – $\frac{BTU}{hr\text{-}ft^2\text{-}°F}$

C = perimeter of the finned section = 44 inches

A = cross sectional area of the finned section – 2.34 in²

L = one half of the length of the finned heat exchanger

$\theta_o = T - T_f$
(°F)

Assume that a Rotron Muffin Type fan is used & Q_{cfm} = 90 ft³/min

Calculating the temperature rise of the air through the enclosure at 466.8 watts dissipation & 90 cfm inlet air at 140°F

$Q_H = \dot{m} c_p \Delta T$

at 140°F ρ_{air} = .0661, C_p = .24 $\frac{BTU}{lb\text{-}°F}$

$$(466.8)(3.41)\frac{BTU}{hr} = \frac{90\,ft^3}{min} \times \frac{60\,min}{hr} \times .24\frac{BTU}{lb\text{-}°F}(.0661)\frac{lb}{ft^3}($$

$$\Delta T_{°F} = \frac{466.8(3.41)}{(90)(60)(.24)(.0661)} = 18.6°F$$

$$\therefore T_f(\text{mean}) = 140°F + \frac{18.6}{2} \doteq 149.3$$

$$\therefore \theta_o = T - T_f = 196.9 - 149.3 = 46.7°F$$

$$\text{Velocity} = \frac{Q_{cfm}}{A} = \frac{90(144)}{(4.5)^2} = 640 \text{ fpm}$$

Reynolds Number (N_{RE}) $= \dfrac{V L_1 \rho}{\mu}$

Assume $L_1 = 3.0''$

@ $T_{f_{mean}} = 150°F$ $\quad \rho = .0650$ lbs/ft³

$\mu = .0495 \dfrac{lb}{ft\text{-}hr}$ & $k = .0170 \dfrac{BTU}{hr\text{-}ft^2\text{-}°F/ft}$

$$N_{RE} = \frac{(640)(60)(3)(.0650)}{12(.0495)} = 1.26 \times 10^4$$

Therefore the flow is laminar & the following equation is applicable –

$$h = \frac{K}{L}(.664)(N_{RE})^{1/2}(N_{PR})^{1/3}$$

N_{PR} @ 150°F = .7

$$h = \frac{.0170\,(12)}{3}(.664)(1.26\times10^4)^{.5}(.7)^{.33}$$

$$h = 4.50 \ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

$$m = \sqrt{\frac{hC}{KA}} = \sqrt{\frac{(4.5)(44)(144)}{(12)(90)(2.34)}} = 3.359$$

Substituting in equation #1

$$Q = K\,m\,A\,\theta_0 \operatorname{Tanh}(mL)$$

$$\frac{155.6\,(3.41)}{4} = \frac{(90)(3.359)(2.34)}{144}(46.7)\operatorname{Tanh}[3.\ldots$$

$$\operatorname{Tanh}[3.359L] = .578$$

$$3.359L = \operatorname{Tanh}^{-1}(.578) = .659$$

$$L = .196 \ ft = 2.357 \ inches$$

or Total Length Req'd = 2(2.357)

= 4.71" min. (Two req'd per leg)

Summarizing the applicable eqns. and incorporating the constants for 140°F inlet air -

② $$\left[\Delta T_{(°F)} = \frac{3.583\ W_T}{Q_{cfm}} \right]$$

Where -

ΔT = Rise in cooling air Temp.

W_T = Total power dissipation in the enclosure

Q_{cfm} = fan flow rate

③ N_R Reynolds No. $= \frac{VLP}{\mu} = \frac{(V_{fpm})(L_{inches})(.0661)(6\ldots}{12\ (.0495)}$

$$\left[N_R = 6.678\ (V_{fpm})(L_{inches}) \right]$$

For laminar flow -

$$h = \frac{K}{L}(.664)(N_{RE})^{1/2}(N_{PR})^{1/3}$$

$$h = \frac{(.0170)(.664)(N_{RE})^{1/2}(.7)^{1/3}(12)}{L_{(in)}}$$

④ $$\left[h = \frac{.120\ (N_{RE})^{1/2}}{\ldots} \quad \frac{BTU}{h\ ft^2\ °F} \right]$$

$$Q = K\, m\, A\, \theta_o \operatorname{Tanh}(mL)$$

(5) Where $m = \sqrt{\dfrac{hc}{KA}}$

$\theta = 46.7\ ^\circ F$ (max)

For an aluminum section —

$K = 90$ BTU/hr-ft²-°F/ft

$$\left[m = \sqrt{\frac{h\, c\, (144)}{(12)(90)(A)}} = \sqrt{\frac{.133\, hc}{A}} \right]$$

$$Q_{watts}(3.41) = 90\, m\, \frac{A_{in^2}}{144}(46.7) \operatorname{Tanh}(mL)$$

(6) $$\left[\operatorname{Tanh}(mL) = \frac{.1168\, Q_{watts}}{m (A_{in^2})} \right]$$

Where Q_{watts} = one half the power dissipated on the heat exchanger & L = one half the required length, in feet.

Assuming a 6" box and
one Rotron Fan ($Q = 90$ cfm)
#E520 Heat sink section - 3" Long
$A = 2.142$ in^2 ($C = 48.1$ in. perimeter)

$$V = \frac{Q}{A} = \frac{90}{(6 \times 4.7 - 2(2.142))} = 542 \text{ fpm}$$

$$N_R = 6.678\, V L = 6.678(542)(3)$$
$$= 1.085 \times 10^4$$

$$h_c = \frac{(.120)(1.085)^{1/2}}{3} = 4.17$$

$$m = \sqrt{\frac{(.133)\, h\, C}{A}} = \sqrt{\frac{(.133)(4.17)(48.1)}{2.142}}$$

$$m = 3.529$$

$$\tanh(mL) = \frac{.1168\, Q}{m A}$$

$$\tanh(3.529 L) = \frac{.1168(155.6)}{(3.529)(4)(2.142)} = .601$$

$$3.529 L = \tanh^{-1} .601 = .6948$$

$$L = .197'$$

$\therefore$ Total Length $= .197 \times 2 \times 12 = 4.73$"

Box Length (min) $= (4.73)(3) + 1.5 \approx 16$"

Fan & Heat exchanger Volume –

6" × 16" × 4.75" – 30 HP (240 V)

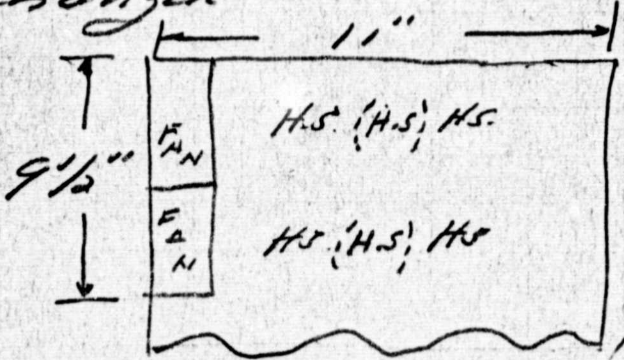
Six heat sinks required (3 on The Top, 3 on The BTM)

Using Heat sink style E520 with Two muffin fans in parallel –

$$V = \frac{Q}{A} = \frac{90 \times 2\ (144)}{[(6)(4.7)(2) - 4(2.140)]} = 542 \text{ fpm}$$

$m = 3.529$ (no change)

$L = 4.73"$ min for each heat exchanger –



Length = 1.5 + 4.75(2) = 11" min (Box – 6" × 11" × 9.75")

Six Heat exchangers again required, Four mounted on the base, Two on the cover –

Considering the #E615 section heat sink - $A = 3.425 \text{ in}^2$

$C = 71.4$ inches perimeter

Assume $L = 2.5$ - Two Fans in parallel

$$V = \frac{(90 \times 2)(144)}{[(6)(4.7)(2) - 2(3.425)]} = 523 \text{ fpm}$$

$$HR = 6.678\, V L = (6.678)(523)(2) = 6985$$

$$h_c = \frac{.100}{2.5}(HR)^{1/2} = \frac{.100}{2.5}(6985)^{1/2} = 4.01$$

$$m = \sqrt{\frac{.133\, h C}{A}} = \sqrt{\frac{(.133)(4.01)(71.4)}{3.425}} = 3.335$$

$$\operatorname{Tanh}(mL) = \frac{.1168\, Q}{m A}$$

$$\operatorname{Tanh}(mL) = \frac{(.1168)(155.6)}{4\,(3.325)(3.425)} = .398$$

$3.335\, L = .422$

$L = .1267$

$L_T = (.1267)(2)(12)" = 3.04"$

∴ Could use Two muffin fans, Six heat sinks (3" Long ea.) Box size

II 30 HP, 480 Volt Case

$\Sigma R_{th} = R_{J-C} + R_{case\ to\ H.S.}$

$= .35 + .40 = .75\ °C/W$
(as before)

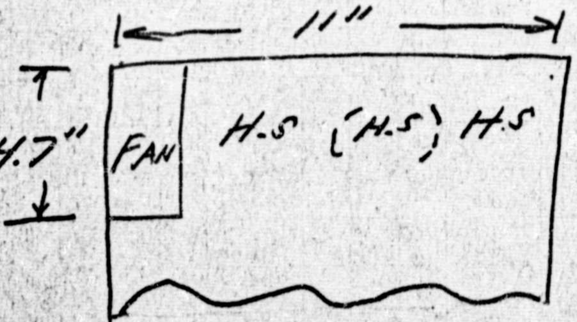
Power dissipation $= \dfrac{155.6}{2} = 77.8$ watts per leg

Assuming a 150°C max junction temperature – T(inlet air) = 140°F

$T_{heat\ sink\ max} = 150°C - Q\Sigma R$

$= 150°C - (77.8)(.75) = 91.65°C$
(196.9°F)

Assume one diode and heat exchanger per leg – all flow rate parameters are the same per heat exchanger as in the prior case –



E520 Heat sink 4.75" Long – Three reqd. 2 on the base, one on the cover –

... 2-3" # E615 base mounted

III 20 HP - 240 V case

Power per leg - 103.7 watts

$\Sigma R_{thermal} = R_{J-c} + R_{case\ to\ HS}$

$= .35 + .4 = .75\ ^\circ C/watt$

(Same case size & R_{J-c} as in the 30 H.P. instance)

$T_{Heatsink\ (max)} = 150^\circ C - Q(\Sigma R)$

$= 150^\circ C - (103.7)(.75) = 72.2^\circ C$

$= 162^\circ F$

$\theta_0 = T_{HS} - T_{air} = 162 - 140 = 22^\circ F$

Considering E615 Heat Sink

$A_s = 3.425\ in^2 \quad C = 71.4$

Two fans in parallel -

$V = \frac{Q}{A} = \frac{90(2)(144)}{(6)(4.7)(2) - 2(3.425)} = 523\ fpm$

Assume $L = 4''$

$N_R = \frac{VL\rho}{\mu} = 6.678\,VL = 6.678(523)(4)$

$= 13970$

$$h_c = \frac{.122}{4}(13970)^{1/2} = 3.54\ \frac{BTU}{hr\text{-}ft^2\,^\circ F}$$

$$m = \sqrt{\frac{.133\, h_c E}{A}} = \sqrt{\frac{(.133)(3.54)(71.4)}{3.425}}$$

$$m = 3.133$$

$$Q = K\, m\, A\, \theta_0 \tanh(mL)$$

$$\frac{108.7}{2}(3.41) = (90)(3.133)\frac{(3.425)}{144}(\theta_0)\tanh(mL)$$

where $mL = (3.133)\left(\frac{4}{2 \times 12}\right)$

$\theta_0 = 54.99^\circ F$ which is in excess of the $22^\circ F$ allowable -

Assume #E605 section heat sink - $A_s = 4.325$, $C = 81.9\ in^2/in$

$$V = \frac{Q}{A} = \frac{(90)(2)(144)}{[(6)(10) - 2(4.325)]} = 504\ \frac{ft}{min}$$

Assume a 6" Length -

$$HR = 6.678\, P\, V\, L = (6.678)(504)(6)$$

$$= 20{,}194$$

$$h_c = \frac{.120}{L}(N_R)^{1/2} = \frac{.120}{6}(20{,}194)^{1/2}$$

$$= 2.842 \quad \frac{BTU}{hr\text{-}ft^2\,°F}$$

$$m = \sqrt{\frac{.133\,h_c\,C}{A_s}} = \sqrt{\frac{(.133)(2.842)(81.9)}{4.325}}$$

$$m = 2.675$$

$$Q = K\,m\,A\,\theta_0\,\mathrm{Tanh}\,(mL)$$

$$\frac{103.7}{2}(3.41) = (90)(2.675)\frac{(4.325)}{144}\,\theta_0\,\mathrm{Tanh}\left[2.675 \times \frac{6}{24}\right]$$

$$\theta_0 = 41.85\ °F$$

Which would Result in a junction Temperature of $150°C + \frac{41.85 - 22}{1.8} = \underline{161°C}$

If $L = 7''$ (same H.S)

$$N_R = 6.678\,VL = (6.678)(504)(7)$$

$$= 23{,}559$$

$$h_c = \frac{.120}{L}(N_R)^{1/2} = \frac{.120}{7}(23{,}559)^{1/2} = 2.63$$

$$m = \sqrt{\frac{.133\,h_c\,C}{A_s}} = \sqrt{\frac{(.133)(2.63)(81.9)}{4.325}} = 2.574$$

$$Q = k\, m A\, \theta_0 \operatorname{Tanh}(mL)$$

$$\left(\frac{103.7}{2}\right)(3.41) = (90)(2.574)\frac{(4.325)}{144}\theta_0 \operatorname{Tanh}\left[\frac{2.574(7}{24}\right]$$

$$\theta_0 = 39.98°F$$

$$T_j = 150°C + \frac{39.98 - 22}{1.8} = \underline{159°C}$$

If the 159°C junction temperature is unacceptable - then two diodes per leg will be required and the smaller heat exchanger could be used - The box size for the #E605 H.S. (3 req'd each 7" long) would be 6" × 10" × 16" for cooling volume -

Consider two diodes per leg,

6 heat sinks of the E615 type 3" long - $A_s = 3.425$ $C = 71.4$ in²/in

Two fans

$$V = \frac{Q}{A} = \frac{(50)(2)(144)}{\left[(6)(4.75)(2) - 2(3.425)\right]} = 517 \text{ ft/min}$$

$$T_{HS}\ (max) = T_J - Q(\Sigma R)$$
$$= 150°C - (51.9)(.75) = 111.08°C$$
$$= 232°F$$

$$\theta_o = 232 - 140°F = 91.9°F$$

$$h_c = \frac{.120}{L}(NR)^{1/2}$$

$$NR = (6.678)VL = (6.678)(517)(3) = 10,356$$

$$h_c = \frac{.120}{3}(10,356)^{1/2} = 4.07\ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(4.07)(71.4)}{3.425}} = 3.3592$$

$$Q = k\, m\, A\, \theta_o \tanh(mL)$$

$$\left(\frac{51.9}{2}\right)(3.41) = 90(3.3592)\left(\frac{3.425}{144}\right)\theta_o \tanh\left[3.3592 \times \frac{3}{24}\right]$$

$$\theta_o = 31.00\ °F$$

which is much less than required

Assume two diodes per line again using H.S. section E102 - 1.5" long

$A_s = 1.792$, $C = 38.7$ in²/in

& one fan

$$V = \frac{Q}{A} = \frac{(90)(144)}{(6)(4.75)} = 454 \text{ cfm}$$

$$NR = 6.678 VL = (6.678)(454)(1.5)$$
$$= 4547$$

$$h_c = \frac{.120}{L}(NR)^{1/2} = \frac{.120}{1.5}(4547)^{1/2}$$
$$= 5.39$$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(5.39)(3.87)}{1.792}} = 3.9346$$

$$Q = K m A \theta_0 \text{ Tanh } (mL)$$

$$\left(\frac{51.9}{2}\right)(3.41) = (90)(3.9346)\frac{(1.792)}{144}\theta_0 \text{ Tanh}[3.934$$

where $L = \frac{1.5}{24}$

$$\theta = 83.3°F$$

∴ The Six 1½" Long, Section # E102 is acceptable - one Rotron muffin Type fan required.
Box size 6" × 11" × 4.75

IV 20 HP - 480 Volts per leg with one diode per leg, each diode dissipating 51.9 watts,

The previous heat sink (1.5" Long, # E102 section) & one fan will Result in an acceptable Diode Junction Temperature. i.e. Three heat sinks will be Required in This case — box size fan cooling provisions will be 6" × 8" × 4.75"

V 10 HP – 240 V per Leg

$R_{J-C} = 1.0\ °C/W$

Contact area $= \dfrac{\pi D_B^2}{4} - \dfrac{\pi D_S^2}{4}$

$D_B = .5"$ DIA $\quad D_S = 1/4"$ DIA

$$A_C = \frac{\pi}{4}\left[.5^2 - .25^2\right] = .1875\ in^2$$

$$\underset{\text{Contact}}{\Sigma R_{th}} = \underset{(.002"\ THK)}{R_{mica}} + \underset{\text{grease} - .001"\ THK}{R_{silicone}}$$

$$\Sigma R_{th} = \Sigma \frac{L}{KA}$$

$$= \frac{.002\,(144)\,(3.41)}{(12)(.34)(.1875)(1.8)} + 2\left[\frac{(.001)(144)(3.41)}{(12)(.45)(.1875)(1.8)}\right]$$

$R_{th} = .71 + .54 = 1.25$ °C/watt

This number appears to be a bit high — Telecon with RCA resulted in a value of 1.0 °C/watt

$\therefore T_{heat\ sink,\ max} = 150°C - Q(\Sigma R)$

$= 150°C - 51.8\,W\,(1.0 + 1.0)\,°C/W$

$= 46.4°C\ (115.50°F)$

The maximum heat sink temperature is less than the 140°F inlet cooling air, therefore two diodes per line will be required

Power per diode $= \frac{51.8}{2} = 25.9$ watts

with two diodes per leg (240V)

$T_{heat\ sink\ (max)} = 150°C - 25.9(2) = 98.2°C$

$= \underline{208.8°F}$

$\theta_0 = T_{HS} - T_{air} = 208.8°F - 140°F = 68.8°F$

Considering a #E101 section heat sink — A = 1.050 C = 26.9 inch perimeter

$$V = \frac{Q}{A} = \frac{90(144)}{(6)(4.75)} = 454 \text{ ft./min}$$
(one fan)

$$N_R = 6.678 VL = 6.678(454)(1.5)$$
$@ L = 1\tfrac{1}{2}"$

$$N_R = 4548$$

$$h_c = \frac{.120}{L}(N_R)^{1/2} = \frac{.120}{1.5}(4548)^{1/2} = 5.39$$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(5.39)(26.9)}{1.058}} = 4.2693$$

$$Q = k_s m A \theta_0 \text{ Tanh}(mL)$$

$$\left(\frac{25.9}{2}\right)(3.41) = (90)(4.2693)\frac{(1.058)}{144}(\theta)\text{ Tanh}\left[4.2693 \times \frac{1}{(12)}\right.$$

$\theta = 60°F$ - which is acceptable

Therefore - for the 10 HP, 240 V condition use 2 diodes per leg, each with a #E101 section, 1.5" Long -

Box size for cooling - (one fan)
6" × 11" × 4.75"

or 6" × 8" × 4.75 if three of the heat sinks are mounted on the

VI 10 HP - 48 Volt per leg -

With one diode per leg the power dissipation is 25.9 watts per diode. From the prior calculations - Three heat sinks will be required (Type E 101, 1½" Long)

One Fan, Box Size 6" x 8" x 4.5" for cooling components.

VII 5 H.P. - 240 Volts per leg.

Power Dissipation per Leg is 29.6 watts.

$R_{J-C} = .9\,^\circ C/W$

$R_{C\text{-}Heatsink} = 1.0\,^\circ C/\text{watt}$ (REF RCA)

$$T_{\substack{Heat\ sink\\(max)}} = 150^\circ C - Q(\Sigma R)$$

$$= 150^\circ C - 29.6(1.0 + .9)$$

$$= 93.76^\circ C\ (200.7^\circ F)$$

$$\theta_{\substack{0\\(max)}} = T_{HS} - T_F = 200.7^\circ F - 140^\circ F = 60.7^\circ F$$

Assuming one Muffin Type fan and a #E101 Type Heat sink 1½" Long - From The calculations presented in Section V -

$V = 454$ ft/min, $N_R = 4548$

$h_c = 5.39$, $m = 4.2693$

$Q = km A \theta_0 \tanh(mL)$

$$\left(\frac{29.6}{2}\right)(3.41) = 90(4.2693)\frac{(1.058)}{144}\theta_0 \tanh\left[4.2693\left(\frac{1.5}{24}\right)\right]$$

$\theta_0 = 68.57\,°F$

which exceeds The 60.7 max allowable -

Trying $L = 2''$

$$h_c = \frac{.120}{L}(N_R)^{1/2}$$

$$N_R = 6.678 VL = 6.678(454)(2) = 6064$$

$$h_c = \frac{.120}{2}(6064)^{1/2} = 4.672$$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(4.672)(26.4)}{1.058}} = 3.974$$

$$Q = \sqrt{\ } m A \theta_0 \tanh(mL)$$

$$\left(\frac{29.6}{2}\right)(3.41) = (90)(3.974)\frac{(1.058)}{144}\theta_0 \tanh\left[3.974\frac{(2)}{24}\right]$$

$\theta_0 = 60.05$ which is acceptable

∴ The 2" Long #E101 section is acceptable - one heat sink per diode - (& muffin type Fan) Box size - 6" x 8" x 4.5" for cooling components will be Required

Considering a Free Convection System and assuming an E615 Type section, $C = 71.4$ in, $A_s = 3.425$

$L = 3$" Long -

Assume $\Delta T °F = 60°F$

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} \text{ for vertical plate}$$

$$h_c = .29\left[\frac{60}{3}(12)\right]^{1/4} = 1.14 \ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

$$Q = h_c A_1 \Delta T$$

$$29.6(3.41) = (1.14)\left(\frac{A_1}{144}\right)(60)$$

$A_{1_{min}} = 212.5 \text{ in}^2$

$C = 71.4 \quad L = 3''$

$CL = (71.4)(3) = 214 \text{ in}^2$

which is about equal to the 212.5 minimum area req'd.

∴ Could use no fan and three 3" sections of #E615 (one per diode) and mounted vertically in the 3" dimension

Box Size = 6" × 9" × 4.75"

VIII 5 HP – 480V condition

Power dissipation per Leg = 14.8 W

$R_{J-C} = .9\,°C/W \; ; \; R_{C-HS} = 1.0\,°C/W$

$T_{Heatsink_{max}} = 150°C - Q(\Sigma R)$

$= 150°C - (14.8)(1.0+.9)$

$= 121.88°C \; (251.38°F)$

$\theta = T_{HS} - T_f = 251.4 - 140 = 111.4°F$

Assuming a 3" Long fin –

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left[\frac{111.4}{3}(10)\right]^{1/4}$$

$$= 1.33 \ \frac{BTU}{hr\text{-}ft^2\,°F}$$

Assuming an E102 section $L = 3''$

$C = 38.7 \quad A_s = 1.792$

$Q = h_c A_1 \Delta T$

$$(14.8)(3.41) = (1.33)\left(\frac{A_1}{144}\right)(111\,°F)$$

A_1 min req'd $= 49.2$ in^2

$CL = 38.7(3'') = 116.1''$ which is more than required

Trying a 1.5" Long section - #E101
$C = 26.9$

$$h_c = .29\left[\frac{111}{1.5}(10)\right]^{1/4} = 1.58 \ \frac{BTU}{hr\text{-}ft^2\,°F}$$

$$(14.8)(3.41) = (1.58)\left(\frac{A_1}{144}\right)(111\,°F)$$

A_1 min req'd $= 41.4$

$CL = 26.9(1.5) = 40.35$

which is very close to the 41.4 min

Radiation was not considered in the analysis –

∴ Three heat sinks, one per diode, vertically mounted, of the #E 101 section – 1.5" long will be required

Box size – 4" × 5" × 4.5"

for cooling components –

<u>XI</u> 1 HP – 240V per leg

Power Dissipation per leg – <u>5.93</u>

$R_{J-C} = 1.0\ ^\circ C/W \quad R_{C-HS} = 1.0\ ^\circ C/W$

$$T_{\text{Heat sink (max)}} = 150^\circ C - Q(\Sigma R)$$
$$= 150^\circ C - 5.93(1.0 + 1.0)$$
$$= 138.14^\circ C\ (280^\circ F)$$

$$\theta = T_{HS} - T_f = 280 - 140 = 140^\circ F$$

For a vertical plane surface –

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = .29\left(\frac{140}{6}(12)\right)^{1/4}$$

Assuming $L = 6"$

BTU/hr ft² °F

Assume that the plate geometry is such that

$A_s = .125(6) = .75$ and $C = 6$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(1.186)(6)}{.75}} = 1.123$$

$$Q = K m A \theta_o \tanh(mL)$$

$$L = \frac{3''}{12} = .25$$

Assume also that all three diodes are mounted on the same plate —

$$\frac{(5.93)(3)(3.41)}{2} = (90)(1.123)\frac{(.75)}{144}\theta_o \tanh(1.123 \times$$

$\theta_o = 210.6\,°F$ which exceeds the $\theta = 140°F$ max allowable —

If radiation to a 140°F environment is considered —

Assume that $T_{HS} = 240°F\ (700°R)$ and $T_{ambient} = 140°F\ (600°R)$

$$h_R = .1714 \times 10^{-2} \times F_e F_a \left[\frac{T_1}{100} + \frac{T_2}{100}\right]\left[\left(\frac{T_1}{100}\right)^2 + \left(\frac{T_2}{100}\right)^2\right]$$

Assume $F_a = 1.0$ & $F_e = .9$

$$h_R = (.1714 \times 10^{-2})(.9)\left[\frac{700}{100} + \frac{650}{100}\right]\left[\left(\frac{700}{100}\right)^2 + \left(\frac{650}{100}\right)^2\right]$$

$h_R = 1.70$

$\therefore h_T = h_c + h_R = 1.186 + 1.70 = 2.89 \ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$

$$m = \sqrt{\frac{.133\, h_c C}{A}} = \sqrt{\frac{(.133)(2.89)(6)}{.75}} = 1.7536$$

$Q = K m A \theta_o \,\text{Tanh}(mL) \qquad L = .25'$

$$\frac{(5.93)(3)(3.41)}{2} = 90\,\theta_o (1.7536)\frac{(.75)}{144}\,\text{Tanh}\left[1.7536(.$$

$\theta_o = 89\ °F$ which is Low

Then the $\theta = 140°F$ max allowable

$$T_{x=.25'} = T_f + \frac{T_{x=0} - T_f}{\text{Cosh}\, mL}$$

Since from the above θ_o is

in The Range of 89°F To 140°F

Assume $\theta_o = 100°F$, i.e. $T_o = 240°F$

$$T_{x=.25'} = 140°F + \frac{100}{\cosh(1.43 \times .25)}$$

Assuming $m = \frac{1.123 + 1.7536}{2} = 1.43$

$$T_{x=.25'} = 140°F + 93.9 = 233.9°F$$

∴ The Temperature gradient is minimal in the L direction, $(240 - 233.9 \doteq 6°F)$

Assuming $\theta_o = 80°F$

i.e. $T_{HS} - T_f = 80 F$

$$T_{HS} = 115 + T_f = 80 + 140 = 220°F$$

$$h_c = .29\left(\frac{\Delta T}{L}\right)^{1/4} = (.29)\left[\frac{80}{6}(12)\right]^{1/4}$$

$$h_c = 1.03 \text{ BTU/hr}\cdot\text{ft}^2\text{-°F}$$

$T_{HS} = 220 \; (680°R) \quad T_a = 140°F \; (600)°R$

$$h_R = .1714 \times 10^{-2} \times .9\left[6.8 + 6\right]\left[6.8^2 + 6^2\right]$$

$$h_R = 1.624 \text{ BTU/hr}\cdot\text{ft}^2\text{°F}$$

$h_T = h_R + h_c = 1.624 + 1.03 = 2.654$

$$m = \sqrt{\frac{.133 h_c C}{A}} = \sqrt{\frac{(.133)(2.654)6''}{.75}} = 1.680$$

$$Q = K m A \theta_o \operatorname{Tanh}(mL)$$

$$\frac{(5.93)(3)(3.41)}{2} = 90(1.680)\frac{(.75)}{144}\theta_o \operatorname{Tanh}(1.680 \times .2$$

$\theta_o = 97$

$\therefore$ θ_o is in the Range of 89°F To 97°F

$\therefore$ T_{HS} max $= 140 + 97 = 237°F$ (114°C

& $T_{junction} = 114°C + Q(\Sigma R_{th})$

$= 114°C + 5.93(2.0)$

$= 125°C$ which is acceptable –

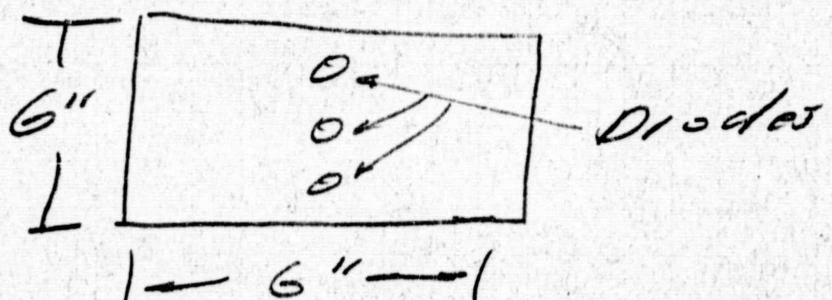
$\therefore$ heat sink for The 1 HP 240 V (& 480 V) condition should be a 6" × 6" × .125" THK plate anodized per Mil-A-8625 Type I

Class 2, dyed black – The Three

diode should be mounted in
the center of the plate —

Summary of The
Heat exchanger
Configurations –

I   1 HP – 240 & 480V
Free convection – Flat
plate 6" x 6" x .125" THK
(aluminum) Black anodize



II   5 HP

a) 480 volt – Free convection
IERC section # E101 - 1.5"
Long – one per diode per
heat sink – Box size 4" x 5" x 4.5
(for cooling only)

b) 240 volt

1) Free convection – Three
3" sections # E615 mounted
vertically – Box size 6" x 9" x 4.

2) Forced convection
Three #E101 sections
each 2" Long & one
Muffin fan - Box Size
6" X 8" X 4.75"

III 10 HP

a) 440 volts - Three Type
E101 heat sinks 1½" Long
One muffin fan
6" X 8" X 4.75"

b) 240 volts - Use Two
diodes per Leg - one
heat sink per diode,
Section #E101 - 1.5" Long
One Muffin Type fan
Box Size 6" X 11" X 4.75" OR
6" X 8" X 4.75" if the heat
sinks are mounted to the
cover

IV 30 HP —

a) 480 volts — one diode per line, Three heat sinks Type E102, 1.5" Long, box Size 6"×8"×4.25" — One Muffin Fan

b) 240 volt — Two diodes per Leg — 6 heat sinks 1.5" Long Type "E102"
& One muffin Type Fan — Box, 6"×11"×4.25"

c) 240 volt — one diode per Leg Three Heat exchangers Type E605 7" Long, Two Rotron Fans Box Size 6"×10"×16"

V 30 H.P.

a) 480 volt — one muffin Type Fan one diode per Leg — Three (cont.)

Type # E520 Type sections 4.75" Long - Two on The base one on The Cover -

box size - 6" x 11" x 4.75"

b) 240 volts. - Two diodes per Leg - Two fans Six heat exchangers Type # E520 - 4.75" Long

Box Size - 6" x 11" x 9.5"

APPENDIX L

ENERGY SAVINGS

1 HP — 1500 HOURS/YR

	EFF (w/o MPC)	$\left(\frac{89.52}{EFF}\right)$ in $/YR.	EFF (w MPC)	$\left(\frac{89.52}{EFF}\right)$ in $/YR.	Δ in $/YR
FL	0.650	$ 137.72	0.700	$ 127.89	$ 9.83
3/4L	0.550	162.76	0.650	137.72	25.04
1/2L	0.400	223.80	0.550	162.76	61.04
1/4L	0.300	298.40	0.500	179.04	119.36
NL	0.150	596.80	0.400	223.80	373.00

AVG: $117.65/YR.

5 HP — 1500 HOURS/YR

	EFF (w/o MPC)	$\left(\frac{447.60}{EFF}\right)$ in $/YR	EFF (w MPC)	$\left(\frac{447.60}{EFF}\right)$ in $/YR	Δ in $/YR
FL	0.770	$ 581.30	0.820	545.85	35.45
3/4L	0.650	688.62	0.750	596.80	91.82
1/2L	0.500	895.20	0.650	688.62	206.58
1/4L	0.400	1,119.00	0.600	746.00	373.00
NL	0.200	2,238.00	0.450	994.67	1,243.33

AVG: $390.04/YR

20 HP — 1500 HOURS/YR.

	EFF (w/o MPC)	$\left(\frac{1790.40}{EFF}\right)$ in $/YR	EFF (w MPC)	$\left(\frac{1790.40}{EFF}\right)$ in $/YR	Δ in $/YR
FL	0.825	2,170.18	0.825	2,170.18	-0-
3/4L	0.700	2,557.71	0.750	2,387.20	170.51
1/2L	0.600	2,984.00	0.680	2,632.94	351.06
1/4L	0.450	3,978.67	0.570	3,141.05	837.62
NL	0.300	5,968.00	0.460	3,892.17	2,075.83

AVG: $687.00/YR

ENERGY SAVINGS

50 HP — 1500 HOURS / YR

	EFF (w/o MPC)	(4476.00 / EFF) in $/YR	EFF (w MPC)	(4476.00 / EFF) in $/YR	Δ in $/YR
FL	0.875	5,115.43	0.875	5,115.43	-0-
3/4 L	0.800	5,595.00	0.850	5,265.88	329.12
1/2 L	0.650	6,886.15	0.730	6,131.31	754.64
1/4 L	0.500	8,952.00	0.620	7,219.35	1,732.65
NL	0.350	12,788.57	0.510	8,776.47	4,012.10

AVG: $1,365.70/YR

125 HP — 1500 HOURS / YR

	EFF (w/o MPC)	(11,190.00 / EFF) in $/YR	EFF (w MPC)	(11190.00 / EFF) in $/YR	Δ in $/YR
FL	0.910	12,296.70	0.910	12,296.70	-0-
3/4 L	0.850	13,164.71	0.880	12,715.91	448.80
1/2 L	0.700	15,985.71	0.750	14,920.00	1,065.71
1/4 L	0.600	18,650.00	0.680	16,455.88	2,194.12
NL	0.400	27,975.00	0.520	21,519.23	6,455.77

AVG: $ 2,032.88/Y

FL					
3/4 L					
1/2 L					
1/4 L					
NL					

ENERGY SAVINGS

1 HP — 2000 HOURS / YR

	EFF (w/o MPC)	$\left(\frac{119.36}{EFF}\right)$ in \$/YR	EFF (w MPC)	$\left(\frac{119.36}{EFF}\right)$ in \$/YR	Δ in \$/YR
FL	0.650	183.63	0.700	170.51	13.12
3/4L	0.550	217.02	0.650	183.63	33.39
1/2L	0.400	298.40	0.550	217.02	81.38
1/4L	0.300	397.87	0.500	238.72	159.15
NL	0.150	795.73	0.400	298.40	497.33

AVG: \$156.87/YR

5 HP — 2000 HOURS / YR

	EFF (w/o MPC)	$\left(\frac{596.80}{EFF}\right)$ in \$/YR	EFF (w MPC)	$\left(\frac{596.80}{EFF}\right)$ in \$/YR	Δ in \$/YR
FL	0.770	775.06	0.820	727.80	47.26
3/4L	0.650	918.15	0.750	795.73	122.42
1/2L	0.500	1193.60	0.650	918.15	275.45
1/4L	0.400	1492.00	0.600	994.67	497.33
NL	0.200	2984.00	0.450	1326.22	1,657.78

AVG: \$520.05

20 HP — 2000 HOURS / YR

	EFF (w/o MPC)	$\left(\frac{2387.20}{EFF}\right)$ in \$/YR	EFF (w MPC)	$\left(\frac{2387.20}{EFF}\right)$ in \$/YR	Δ in \$/YR
FL	0.825	2,893.58	0.825	2,893.58	⊖
3/4L	0.700	3,410.29	0.750	3,182.93	227.36
1/2L	0.600	3978.67	0.680	3,510.59	468.08
1/4L	0.450	5,304.89	0.570	4,188.07	1,116.82
NL	0.300	7,957.33	0.460	5,189.57	2,767.76

ENERGY SAVINGS

50 HP

2000 HOURS /YR

EFF (w/o MPC)	$\left(\frac{5968.00}{EFF}\right)$ in \$/YR	EFF (w MPC)	$\left(\frac{5968.00}{EFF}\right)$ in \$/YR	Δ in \$/YR
0.875	6820.57	0.875	6820.57	0
0.800	7460.00	0.850	7021.18	438.82
0.650	9,181.00	0.730	8175.34	1,006.20
0.500	11,936.00	0.620	9625.81	2,310.19
0.350	17,051.43	0.510	11,701.96	5,349.47

AVG: 1,820.94/YR

125 HP

2000 HOURS /YR

EFF (w/o MPC)	$\left(\frac{14920.00}{EFF}\right)$ in \$/YR	EFF (w MPC)	$\left(\frac{14920.00}{EFF}\right)$ in \$/YR	Δ in \$/YR
0.910	16,395.60	0.910	16,395.60	0
0.850	17,552.94	0.880	16,954.55	598.39
0.700	21,314.29	0.750	19,893.33	1420.96
0.600	24,866.67	0.680	21,941.18	2,925.49
0.400	37,300.00	0.520	28,692.31	8,607.69

AVG. 2,710.51 /YR

ENERGY SAVINGS

1 HP — 3000 HOURS/YR

EFF (w/o MPC)	(179.04/EFF) in $/YR	EFF (w MPC)	(179.04/EFF) in $/YR	Δ in $/YR
0.650	275.45	0.700	255.77	19.68
0.550	325.53	0.650	275.45	50.08
0.400	447.60	0.550	325.53	122.07
0.300	596.80	0.500	358.08	238.72
0.150	1,193.60	0.400	447.60	746.00

AVG: $ 235.31/YR

5 HP — 3000 HOURS/YR

EFF (w/o MPC)	(895.20/EFF) in $/YR	EFF (w MPC)	(895.20/EFF) in $/YR	Δ in $/YR
0.770	1,162.60	0.820	1,091.77	70.89
0.650	1,377.23	0.750	1,193.60	183.63
0.500	1,790.40	0.650	1,377.23	413.17
0.400	2,238.00	0.600	1,492.00	746.00
0.200	4,476.00	0.450	1,989.33	2,486.67

AVG: $ 780.07/YR

20 HP — 3000 HOURS/YR

EFF (w/o MPC)	(3580.80/EFF) in $/YR	EFF (w MPC)	(3580.80/EFF) in $/YR	Δ in $/YR
0.825	4,340.36	0.825	4,340.36	0
0.700	5,115.43	0.750	4,774.40	341.03
0.600	5,968.00	0.680	5,265.88	702.12
0.450	7,957.33	0.570	6,282.11	1675.22
0.300	11,936.00	0.460	7,784.35	4,151.65

AVG: $ 1,374.00/YR

ENERGY SAVINGS

50 HP — 3000 HOURS / YR

EFF (w/o MPC)	(8952.00 / EFF) in $/YR	EFF (w MPC)	(8952.00 / EFF) in $/YR	Δ in $/YR
0.875	10,230.86	0.875	10,230.86	-0-
0.800	11,190.00	0.850	10,531.76	658.24
0.650	13,772.31	0.730	12,263.01	1,509.30
0.500	17,904.00	0.620	14,438.71	3,465.29
0.350	25,577.14	0.510	17,552.94	8,024.20

AVG: $ 2,731.41

125 HP — 3000 HOURS / YR

EFF (w/o MPC)	(22380.00 / EFF) in $/YR	EFF (w MPC)	(22380.00 / EFF) in $/YR	Δ in $/YR
0.910	24,593.41	0.910	24,593.41	-0-
0.850	26,329.41	0.880	25,431.82	897.59
0.700	31,971.43	0.750	29,840.00	2131.43
0.600	37,300.00	0.680	32,911.76	4,388.24
0.400	55,950.00	0.520	43,038.46	12,911.54

AVG 4,065.76/YR

APPENDIX M

COST/PRICE BREAKDOWN

IVECO

INCLUDES:	CUSTOMER: NASA/MSFC
Ruggedized Industrial Grade (NEMA1)	QUOTE NO: ---
Motor Power Controller	MODEL NO: EY1021A-A/A
Single-Phase, 1 hp, 120VAC, 60 Hz	ITEM NO: 1
	DATE: 3-30-81

(See Attached)

1. MATERIAL:

Material		$ 14.97
Spoilage	3 %	.45
Subcontract		---
Subtotal		$ 15.42
Material Handling	8 %	1.23

TOTAL MATERIAL $16.65

2. DIRECT LABOR:

	Est. Hours	Rate Per Hour	Estimated Cost	
Program Manager				
Engineering Planner				
Electronic Engineer				
Reliability Engineer				
Mechanical Engineer				
Technical Writing				
Design and Drafting				
Engineering Technician				
Fabrication-Prototype				
Assembly-Prototype				
TOTAL ENGINEERING LABOR				$ ---
BURDEN @ ___ %				---
Production Technician	0.10	7.50	.75	
Production Assembly	2.00	4.10	8.20	
Fabrication	0.15	4.25	.64	
Winding				
Q.C. Technician				
Q.C. Engineering				
Analysis				
Inspection	0.20	4.10	.82	
TOTAL MANUFACTURING LABOR				$ 10.47
BURDEN @ 120 %				12.49

3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing) $ 22.90

4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3). 39.55

5. G & A 13.5 % of Line 4 . . . . 5.34

6. SUBTOTAL 44.89

7. PROFIT 15 % of Line 6 . . . . 6.73

8. TOTAL ESTIMATED PRICE . . . . $ 51.62

IVECO

INCLUDES:
Ruggedized Industrial Grade (NEMA 1)
Motor Power Controller
Single-Phase, 5 HP, 240VAC, 60Hz

CUSTOMER: NASA/MSFC
QUOTE NO: ---
MODEL NO: EY1021A-D/B
ITEM NO: 2
DATE: 3-30-81

1. MATERIAL:

Material		$ 17.25
Spoilage	3 %	.52
Subcontract		17.77
Subtotal		1.42
Material Handling	8 %	

(See Attached)

TOTAL MATERIAL . . . . $ 19.19

2. DIRECT LABOR:

	Est. Hours	Rate Per Hour	Estimated Cost
Program Manager			
Engineering Planner			
Electronic Engineer			
Reliability Engineer			
Mechanical Engineer			
Technical Writing			
Design and Drafting			
Engineering Technician			
Fabrication-Prototype			
Assembly-Prototype			

TOTAL ENGINEERING LABOR . . . . $ ---

BURDEN @ ____ % . . . . ---

	Est. Hours	Rate Per Hour	Estimated Cost
Production Technician	0.15	$7.50	$1.13
Production Assembly	2.15	4.10	8.82
Fabrication	0.20	4.25	0.85
Winding			
Q.C. Technician			
Q.C. Engineering			
Analysis			
Inspection	0.22	4.10	0.90

TOTAL MANUFACTURING LABOR . . . . $ 11.70

BURDEN @ 120 % 14.04

3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing) $ 25.74

4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3) 44.93

5. G & A 13.5 % of Line 4 . . . . 6.07

6. SUBTOTAL 51.00

7. PROFIT 15 % of Line 6 . . . . 7.65

8. TOTAL ESTIMATED PRICE . . . . $ 58.65

IVECO

INCLUDES:
Ruggedized Industrial Grade (NEMA 1)
Motor Power Controller
Three-Phase, 10 HP, 240VAC, 60 Hz

CUSTOMER: NASA/MSFC
QUOTE NO: ---------
MODEL NO: EY1027A-E/B
ITEM NO: 3
DATE: 3-30-81

1. MATERIAL:

Material		$ 67.00
Spoilage	3 %	2.01
Subcontract		---
Subtotal		69.01
Material Handling	8 %	5.52

TOTAL MATERIAL . . . . $ 74.53

2. DIRECT LABOR:

	Est. Hours	Rate Per Hour	Estimated Cost	
Program Manager				
Engineering Planner				
Electronic Engineer				
Reliability Engineer				
Mechanical Engineer				
Technical Writing				
Design and Drafting				
Engineering Technician	0.15	$9.00	$1.35	
Fabrication-Prototype				
Assembly-Prototype				
TOTAL ENGINEERING LABOR				$ 1.35
BURDEN @ 140 %				1.89
Production Technician	0.50	7.50	3.75	
Production Assembly	4.25	4.10	17.43	
Fabrication	0.40	4.25	1.70	
Winding				
Q.C. Technician				
Q.C. Engineering				
Analysis				
Inspection	0.50	4.10	2.70	
TOTAL MANUFACTURING LABOR				$ 24.93
BURDEN @ 120 %				29.92

3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing) $ 58.09
4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3) 132.62
5. G & A 13.5 % of Line 4 . . . . 17.90
6. SUBTOTAL 150.52
7. PROFIT 15 % of Line 6 . . . . 22.58
8. TOTAL ESTIMATED PRICE . . . . $ 173.10

IVECO

INCLUDES:
Ruggedized Industrial Grade (NEMA1)
Motor Power Controller
Three-Phase, 10 HP, 480VAC, 60 Hz

CUSTOMER: NASA/MSFC
QUOTE NO: ---
MODEL NO: EY1027A-E/C
ITEM NO: 4
DATE: 3-30-81

1. MATERIAL:

Material		$ 67.00
Spoilage	3 %	2.01
Subcontract		---
Subtotal		69.01
Material Handling	8 %	5.52

TOTAL MATERIAL . . . . $ 74.53

2. DIRECT LABOR:

	Est. Hours	Rate Per Hour	Estimated Cost	
Program Manager				
Engineering Planner				
Electronic Engineer				
Reliability Engineer				
Mechanical Engineer				
Technical Writing				
Design and Drafting				
Engineering Technician	0.20	$9.00	$1.80	
Fabrication-Prototype				
Assembly-Prototype				
TOTAL ENGINEERING LABOR				$ 1.80
BURDEN @ 140 %				2.52
Production Technician	0.60	7.50	4.50	
Production Assembly	4.35	4.10	17.84	
Fabrication	0.50	4.25	2.13	
Winding				
Q.C. Technician				
Q.C. Engineering				
Analysis				
Inspection	0.60	4.10	2.46	
TOTAL MANUFACTURING LABOR				$ 26.93
BURDEN @ 120 %				32.32

3. TOTAL DIRECT LABOR INCLUDING BURDEN (Engineering & Manufacturing) $ 63.57
4. TOTAL DIRECT COSTS PLUS BURDEN (Line 1 plus Line 3). 138.13
5. G & A 13.5 % of Line 4 . . . . 18.65
6. SUBTOTAL 156.78
7. PROFIT 15 % of Line 6 . . . . 23.52
8. TOTAL ESTIMATED PRICE . . . . $ 180.30

MATERIAL LISTS

1Ø, 120VAC, 60 Hz, 1 HP

PCB	$2.50 ea.	1 reqd.	$ 2.50	
Enclosure	3.80 ea.	1 reqd.	3.80	NEMA 1
Triac	2.60 ea.	1 reqd.	2.60	15A, 200V
Heatsink	0.77 ea.	1 reqd.	.77	
Electronics	4.50 ea.	1 reqd.	4.50	
Hardware/Misc.	0.80 ea.	As reqd.	.80	
	Total Material		$14.97/unit	

1Ø, 240VAC, 60 Hz, 5 HP

PCB	$2.50	1 reqd.	$ 2.50	
Enclosure	3.80	1 reqd.	3.80	NEMA 1
Triac	4.45	1 reqd.	4.45	40A, 400V
Heatsink	1.20	1 reqd.	1.20	
Electronics	4.50	1 reqd.	4.50	
Hardware/Misc.	0.80	As reqd.	0.80	
	Total Material		$17.25/unit	

3Ø, 480VAC, 60 Hz, 10 HP

PCB	$5.80	1 reqd.	$ 5.80	
Triacs	8.20	3 reqd.	24.60	
Heatsink	3.20	1 reqd.	3.20	
Enclosure	4.60	1 reqd.	4.60	NEMA 1
Drive Magnetics	3.40	3 reqd.	10.20	40A, 800V
Power Magnetics	4.85	1 reqd.	4.85	
Current Magnetics	1.85	3 reqd.	5.55	
Electronics	9.00	lot	9.00	
Hardware/Misc.	2.20	lot	2.20	
		Total Material	$70.00/unit	